N74-344

ADVANCED AERONAUTICAL CONCEPTS

HEARINGS

BEFORE THE

COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES UNITED STATES SENATE

NINETY-THIRD CONGRESS

SECOND SESSION

JULY 16 AND 18, 1974

pproved for public release

Printed for the use of the
Committee on Aeronautical and Space Sciences

U.S. GOVERNMENT PRINTING OFFICE
38-266 O WASHINGTON : 1974

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price $

Best
Available
Copy

COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES

FRANK E. MOSS, Utah, *Chairman*

WARREN G. MAGNUSON, Washington	BARRY GOLDWATER, Arizona
STUART SYMINGTON, Missouri	CARL T. CURTIS, Nebraska
JOHN C. STENNIS, Mississippi	LOWELL P. WEICKER, JR., Connecticut
HOWARD W. CANNON, Nevada	DEWEY F. BARTLETT, Oklahoma
JAMES ABOUREZK, South Dakota	JESSE A. HELMS, North Carolina
FLOYD K. HASKELL, Colorado	PETE V. DOMENICI, New Mexico

ROBERT F. ALLNUTT, *Staff Director*
JAMES J. GEHRIG, *Professional Staff Member*
GILBERT W. KEYES, *Professional Staff Member*
CRAIG M. PETERSON, *Chief Clerk/Counsel*
H. GERALD STAUB, *Professional Staff Member*
CRAIG VOORHEES, *Professional Staff Member*
DR. GLEN P. WILSON, *Professional Staff Member*
RALPH E. VANDERVORT, Jr., *Assistant Chief Clerk*

CHARLES F. LOMBARD, *Minority Counsel*

CONTENTS

ADVANCED AERONAUTICAL CONCEPTS

TUESDAY, JULY 16, 1974

U.S. SENATE,
COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES,
Washington, D.C.

The committee met, pursuant to notice, at 9:36 a.m., in room 235, Russell Senate Office Building, Senator Frank E. Moss (chairman) presiding.

Present: Senators Moss, Metzenbaum, Goldwater, and Bartlett.

Also present: Robert F. Allnutt, staff director; Craig M. Peterson, chief clerk/counsel; James J. Gehrig, Glen P. Wilson, Craig Voorhees, Jerry Staub, and Gil Keyes, professional staff members; Mary Rita Robbins, clerical assistant; Charles Lombard, minority counsel and Anne Kalland, minority clerical assistant.

OPENING STATEMENT BY THE CHAIRMAN

The CHAIRMAN. The hearing will come to order.

As we begin this morning, I want to take just a minute to acknowledge something that is very much on all our minds. This is U.S. Space Week. Five years ago, just about at this same time, Neil Armstrong, Buzz Aldrin, and Mike Collins lifted off from the Cape on the historic flight of Apollo 11.

Although we are here today to talk about aeronautics, and although we will be having a number of observances of this fifth anniversary this week, I wanted to take just a moment to note our respect for the thousands of men and women who gave so much for all mankind.

Today the committee begins 2 days of hearings to receive testimony on advanced aeronautical concepts.

Aviation plays an exceedingly important role in the affairs of our country. It is one of our largest industries and largest employers. In all of its aspects, it is one of our most technically advanced industries; as a consequence, the United States enjoys a very substantial favorable balance of trade in aerospace products. Without objection there will be included at an appropriate point in the record the table from page 103 of Aerospace Industries' Aerospace Facts and Figures for 1974/75, showing the balance of trade for the years 1960 through 1973. (See p. 2.)

Aviation systems play a major role in transportation, moving people and cargo around the country and between countries, and predictions indicate manifold increases by the end of the century.

For some years now, the United States has been the undisputed world leader in aeronautical technology and systems. We enjoyed this position because our Government, our universities, and our industry pressed the technology and have been innovative in the production and marketing of aeronautical products. To retain a leading position in the future will likewise depend on our technology and on the innovation of our Government, universities and industry leaders in using this technology to meet the needs of the people.

The purpose of these hearings is to examine what the aeronautical R. & D. community is thinking about for the future. We are interested in those things that might possibly provide a quantum jump in aeronautical technology and systems. We do not intend to review what is under development now, but rather, what our leading aviation experts can predict for the future.

Today, we will hear from Government witnesses—from the National Aeronautics and Space Administration, from the Department of the Navy, the Department of the Air Force, and the Department of Transportation.

On Thursday, we will hear from the Department of the Army and from witnesses outside the Government on lighter-than-air vehicles, on new engines and new vehicles, and from a recognized leader in the field of aviation safety.

[The table follows:]

[Reprinted from Aerospace Industries' Facts and Figures for 1974–75]

TOTAL AND AEROSPACE BALANCE OF TRADE, CALENDAR YEARS 1960 TO DATE

[Millions of dollars]

Year	Total U.S. trade balance [1]	Aerospace			Aerospace trade balance as percent of U.S. total
		Trade balance	Exports	Imports	
1960	$5,369	$1,665	$1,726	$61	31.0
1961	6,096	1,501	1,653	152	24.6
1962	5,178	1,795	1,923	128	34.7
1963	6,060	1,532	1,627	95	25.3
1964	7,556	1,518	1,608	90	20.1
1965	5,852	1,459	1,618	159	24.9
1966	4,524	1,370	1,673	303	30.3
1967	4,409	1,961	2,248	287	44.4
1968	1,133	2,661	2,994	333	234.9
1969	1,289	2,831	3,138	307	219.6
1970	2,708	3,089	3,397	308	114.6
1971 [4]	[2] 2,024	3,823	4,196	373	(3)
1972 [4]	−6,331	3,242	3,807	565	(3)
1973	1,567	4,382	5,136	754	279.6

[1] U.S. balance of trade is the difference between exports of domestic merchandise and imports for consumption.
[2] First negative U.S. balance of trade since 1888.
[3] Not applicable.
[4] Revised.

Source: Bureau of the Census, "U.S. Exports, Schedule B Commodity and Country", Report FT 410; "U.S. Imports, General and Consumption, Schedule A Commodity and Country," Report FT 135; "Highlights of U.S. Export and Import Trade," FT 990 (All are monthly publications).

The CHAIRMAN. Before we call our first witness, who will be Dr. Fletcher, Administrator of NASA, I would like to turn to my colleague, Senator Goldwater, and ask him if he has any comments or opening statement.

Senator GOLDWATER. Thank you, Mr. Chairman. I certainly concur with your thoughts about National Space Week. I hope it will serve as a reminder to our fellow Americans of the many benefits that have come from space programs.

We have a vital interest in maintaining a high level of research and development in our country and there seems to be no doubt that there is a relationship between R. & D. spending and improved technology and higher productivity.

Part of the process lies in stimulating innovation. Innovation can only occur when the windows are open and fresh air can come in. And I hope these hearings will help to keep the windows open.

The CHAIRMAN. Thank you very much, Senator. We look forward to hearing from the witnesses we have today and as I indicated, our first witness will be Dr. Fletcher, the Administrator of NASA.

Dr. Fletcher, you and your associates may proceed at this point.

[Biographies of Dr. James C. Fletcher, General Bruce Holloway, Mr. J. Lloyd Jones and Mr. Gerald G. Kayten follow:]

BIOGRAPHY OF JAMES CHIPMAN FLETCHER, NASA ADMINISTRATOR

Dr. James C. Fletcher was sworn in as Administrator of the National Aeronautics and Space Administration in a White House ceremony in the President's office on April 27, 1971.

President Nixon announced Dr. Fletcher's nomination as NASA Administrator on Feb. 27, 1971 and the appointment was confirmed by the U.S. Senate on March 11, 1971.

Dr. Fletcher became President of the University of Utah in 1964 after two decades of leadership in industry, government and military activities.

He was born June 5, 1919 in Millburn, New Jersey, attended high school in Flushing, New York and graduated from Bayside High School, Bayside, New York. He received a B.A. degree in physics with a minor in mathematics from Columbia University in 1940.

After graduation, Dr. Fletcher served as a research physicist with the U.S. Navy Bureau of Ordance, at Port Townsend, Washington, studying the problems of degaussing ships as protection against magnetic mines.

In 1941 he became a special research associate at the Cruft Laboratory of Harvard University. He went to Princeton University in 1942 as a teaching fellow and later was an instructor and research physicist.

At the end of World War II, he began work on a doctorate in physics at the California Institute of Technology under a teaching assistantship and an Eastman Kodak Fellowship. After receiving his Ph. D. degree in 1948, Dr. Fletcher joined Hughes Aircraft Co., Culver City, California, as director of the Theory and Analysis Laboratory in the Electronics Division. Six years later this division—instrumental in developing the Falcon air-to-air missile and the F-102 all-weather interceptor—had grown from 120 to 25,600 employees.

In 1954, Dr. Fletcher joined the Ramo-Wooldridge Corp. as an Associate Director and soon became Director of Electronics in the Guided Missile Research Division. Later the Guided Missile Division became Space Technology Laboratories, a subsidiary of Ramo-Wooldridge, with technical responsibility for all United States intercontinental ballistic missiles (Atlas, Titan and Minuteman), as well as the Thor intermediate range ballistic missile. The laboratories also initiated Pioneer 4, the nation's first space probe.

In July 1958, Dr. Fletcher organized and was first president of the Space Electronics Corp., at Glendale, California, with his associate, Frank W. Lehan.

Space Electronics Corp. developed and produced the Able Star stage of the Thor-Able space carrier and had grown to 300 employees by 1960 when controlling interest was sold to Aerojet General Corp.

A year later, Space Electronics Corp. was merged with the spacecraft division of Aerojet to form the Space General Corp. Dr. Fletcher was responsible for the formation of this new corporation and was its first president. He later became Chairman of the Board of Space General and Systems Vice President of

Aerojet General Corp. He served in this dual capacity until July 1, 1964 when he resigned to become the eighth president of the University of Utah.

In his career as a research scientist, Dr. Fletcher developed patents in areas as diverse as sonar devices and missile guidance systems. He continues his interest in science through national committee work, having served on more than 50 national committees and as chairman of 10.

In March 1967, Dr. Fletcher, after serving as a consultant since its inception in 1958, was appointed by President Johnson to membership on the President's Science Advisory Committee, on which he served for several years.

He was a member of the President's Committee on the National Medal of Science; and of several Presidential Task Forces, the most recent being the Task Force on Higher Education.

He is a Fellow of the Institute of Electrical and Electronics Engineers, an Associate Fellow of the American Institute of Aeronautics and Astronautics and a member of the Board of Trustees of the Theodore von Karman Memorial Foundation. He is a Fellow of the American Academy of Arts and Sciences and of the American Astronautical Society, a member of the Cosmos Club and a member of the Board of Governors of the National Space Club.

He received the first Distinguished Alumni Award to be given by California Institute of Technology and an Honorary Doctor of Science Degree from the University of Utah. Dr. Fletcher served higher education as a member of the Executive Committee of the National Association of State Universities and Land Grant Colleges.

He is the fourth man to head the nation's civilian space agency which came into being October 1, 1958. The first Administrator was Dr. T. Keith Glennan, then president of Case Institute of Technology, Cleveland. He was succeeded in 1961 by Mr. James E. Webb, a former Director of the Bureau of the Budget and Under Secretary of State, who served until 1968. Dr. Fletcher's immediate predecessor was Dr. Thomas O. Paine, who resigned September 15, 1970, to return to the General Electric Company after heading NASA since October 1968.

Dr. Fletcher is married to the former Fay Lee of Brigham City, Utah, and they are the parents of four children, three girls and a boy: Virginia Lee, Mary Susan, James Stephen and Barbara Jo. The Fletchers reside at 7721 Falstaff Road, McLean, Virginia.

Biography of Bruce K. Holloway, General, USAF (Ret.), Assistant Administrator for DOD and Interagency Affairs, Acting Associate Administrator for Aeronautics and Space Technology

Bruce K. Holloway, General, USAF (Ret.) was named Assistant Administrator for DOD Interagency Affairs on March 15, 1974. He also serves as Acting Associate Administrator for Aeronautics and Space Technology.

Holloway, former Commander of the Strategic Air Command, had been appointed a Special Assistant to the Administrator, September 10, 1973. He joined NASA as a consultant to the Administrator on August 13, 1973.

Holloway graduated from the United States Military Academy in 1937 and did postgraduate work in aeronautical engineering at the California Institute of Technology. During World War II he became a fighter ace as a pilot with the famed "Flying Tigers" of the American Volunteer Group in China. He commanded this unit after it was activated as the Army Air Force's 23rd Fighter Group. His distinguished career has included assignments as Commander of the Air Force's first jet-equipped fighter group, Commander of the United States Air Forces in Europe, and Air Force Vice Chief of Staff. His decorations include the Distinguished Service Medal and the Silver Star.

Holloway was born in Knoxville, Tennessee. He is married to the former Frances Purdy of New York and they have three children.

Biography of J. Lloyd Jones, Deputy Associate Administrator (Aeronautics), Office of Aeronautics and Space Technology

J. Lloyd Jones is Deputy Associate Administrator (Aeronautics), Office of Aeronautics and Space Technology, NASA Headquarters, Washington, D.C. He has held the position since 17 June 1974.

In this position, Jones is directly responsible for aeronautical research and technology including aerodynamics and vehicle systems, aeronautical propulsion, aeronautical operating systems, military aircraft programs, transport technology, and the JT8D Refan Program.

Prior to this assignment, Jones was Director, Aerodynamics and Vehicle Systems Division, a position held since 1972. Earlier positions within NASA, all at Ames Research Center, include: Research Assistant to the Director, 1970–1972; Chief, Aeronautics Division, 1965–1970; Chief, Vehicle Aerodynamics Branch, 1962–1965; and Chief, 8 by 7 Foot Supersonic Wind Tunnel Branch, 1954–1962.

Jones graduated from the University of Washington in 1944 with a B.S. in Aeronautical Engineering and received an M.S. in Engineering Science from Stanford in 1952.

Jones, who holds a patent on a supersonic transport aircraft concept, has written a number of technical papers in aerodynamics and fluid mechanics, and is an internationally recognized authority on wind tunnel design and operation.

He is an associate fellow of the American Institute of Aeronautics and Astronautics.

Mr. Jones and his wife, Kathleen, have four children and reside in Annandale, Virginia.

Biography of Gerald G. Kayten

Gerald G. Kayten is Director of the OAST Study and Analaysis Office in NASA Headquarters. Prior to this assignment he directed the Transport Experimental Programs Office. He joined NASA in 1968 after 13 years with the Martin Marietta Corporation in Baltimore, where he served as Chief Aerodynamics Engineer, Chief of Preliminary Design, and Advanced Design program manager. In earlier Government service, he spent 9 years as Head of the Flying Qualities and Flight Test Branch, U.S. Navy Dept. Bureau of Aeronautics, and 6 years in stability and control research at NACA's Langley laboratories.

Mr. Kayten was born in New York, N.Y. and is a graduate of New York University's College of Engineering. He is an Associate Fellow of the American Institute of Aeronautics and Astronautics.

STATEMENT OF DR. JAMES C. FLETCHER, ADMINISTRATOR, NASA, ACCOMPANIED BY J. LLOYD JONES, DEPUTY ASSOCIATE ADMINISTRATOR, NASA; AND GERALD G. KAYTEN, DIRECTOR, STUDY AND ANALYSIS OFFICE, NASA

Dr. Fletcher. Mr. Chairman, Senator Goldwater, I would like to first introduce the two gentlemen appearing with me this morning. To my right, Mr. Lloyd Jones who has recently assumed the duties of Deputy Associate Administrator for Aeronautics in the Office of Aeronautics and Space Technology. On my left Mr. Gerald Kayten, who is the Director of the Office of Study and Analysis, Office of Aeronautics and Space Technology.

Gen. Bruce Holloway, our Acting Associate Administrator for Aeronautics and Space Technology, intended to deliver a brief introductory statement here this morning. Unfortunately, he is unable to testify for he is acting as an honorary pallbearer at the funeral of Gen. Carl Spaatz, whom you will remember was the first Chief of Staff of the Air Force. In his absence I would like to offer his statement for the record and at the end read two brief excerpts from it at the conclusion of my remarks.

The Chairman. Without objection that may be done. It will be included. (See p. 33.)

Dr. Fletcher. I am always pleased to appear before this committee but especially so in a meeting like this one. We are here today not to discuss our budget, our needs, or our problems, but rather to share with you a glimpse into the future of aeronautics—a subject of particular interest to me.

Since my arrival at NASA in 1971 our aeronautics effort, measured in terms of accomplishment as well as research expenditures and peo-

ple, has increased steadily. I would like to be able to report an even greater increase, but I realize, as you do, that our resources are not unlimited and our planning is necessarily influenced by priority needs in many areas. Nevertheless, I believe we have a healthy aeronautical research program in being and I fully expect to see it grow even more so.

Any discussion of advanced aeronautical concepts requires that we project well out into the future. Our confidence in such projections depends largely on how solid a base we use as our starting point—and how well we have performed in the past. In this regard I believe NASA, and NACA before it, can point to a fairly impressive track record. The research conducted in our laboratories and flight facilities, in close cooperation with military services and aeronautical industry, has led to a succession of advances spanning all but the very earliest history of flight These include early NACA accomplishments; for example, airplane drag reduction; the development of a family of airfoil sections used in generations of successful military and civil airplane designs; a series of effective high-lift devices essential to high-performance transport and combat airplane design; the establishment of a data base for high-speed airplane design resulting from the "X-airplane" series of research programs covering swept wings, low-aspect-ratio design, delta wings, and variable sweep; and, more recently the so-called "area rule" which made sustained flight in the transonic speed range practical.

Most recently, the research has produced the supercritical airfoil technology which is now beginning to influence new military and civil designs, and the propulsive-lift concepts shortly to fly in the Air Force Advanced Medium STOL Transport prototype program.

NASA's aeronautical programs provide the essential technology foundations, and contain the seeds from which NASA, the military services, and the industry evolve a variety of advanced concepts. These concepts constitute options for eventual development. Among them are several which will greatly alter the character of future aviation systems, but at this time it is virtually impossible to predit which will actually be developed and produced. This will, of course, depend on the demonstration of technical feasibility, but it will depend also on a combination of economic, social, military, and political considerations which will determine the willingness and ability to finanace the particular undertaking.

Although we cannot predict with confidence where the advanced concepts will lead, we can postulate where they may lead—and we think the prospects are quite exciting. In the remainder of this half hour we will review some of the more interesting concepts and the uses to which they may be put. Since you will be receiving separate military testimony, we will place most of our emphasis on potential civil applications. Mr. Jones will cover the nearer term future, in which significant improvements in the familiar forms of subsonic air transportation appear possible. Mr. Kayten will address the more speculative and farther out future possibilities. We will then be pleased to answer your questions or to provide additional information not included in our statements.

The CHAIRMAN. Thank you. Mr. Jones, will you go ahead?

Mr. JONES. Mr. Chairman, Senator Goldwater, the major trends in aviation over the next two decades will be influenced strongly by commitments already made by the aircraft operators and by technology developments now under way. These developments, particularly those undertaken in response to pressing needs such as energy conservation and environmental improvements, will lead to significant changes in the relatively near-term future.

Toward the end of the century, a new generation of civil transports will be in operation. Most of the wide-body jets of today will have been replaced in trunk-line service, and a greatly expanded and diversified airline market will be served. Air transportation will continue to be economical, environmentally acceptable, and socially beneficial. Aircraft engines, which constitute only a minor factor in pollution, will become even cleaner. Noise impact on the community will be drastically reduced from that of past and present jet aircraft. Above all, the aircraft will be fuel-conservative, an essential feature because the energy shortage and fuel costs will continue to be issues of great importance.

During this time period, advancements are expected in three general areas: operations, short-haul and special-purpose aircraft, and long-haul transports.

A major element in future aeronautics, which contributes to fuel economy, noise reduction, congestion relief, and safety, is a new *approach to operations* (fig. 1). Some of the techniques include steep, curved approaches; reduced separation distances; fewer holds in flight and on the ground; and, improved allweather operations. In later

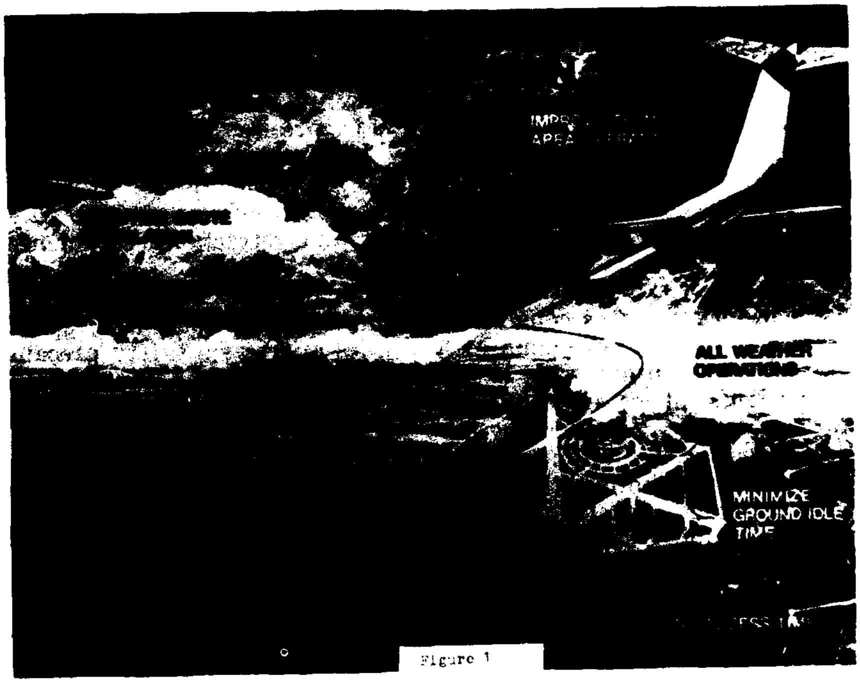


Figure 1

developments, advanced avionics and active controls will permit routine maneuvers which are beyond the capability of an unaided pilot, especially in exploiting the unique terminal-area characteristics of STOL and VTOL aircraft.

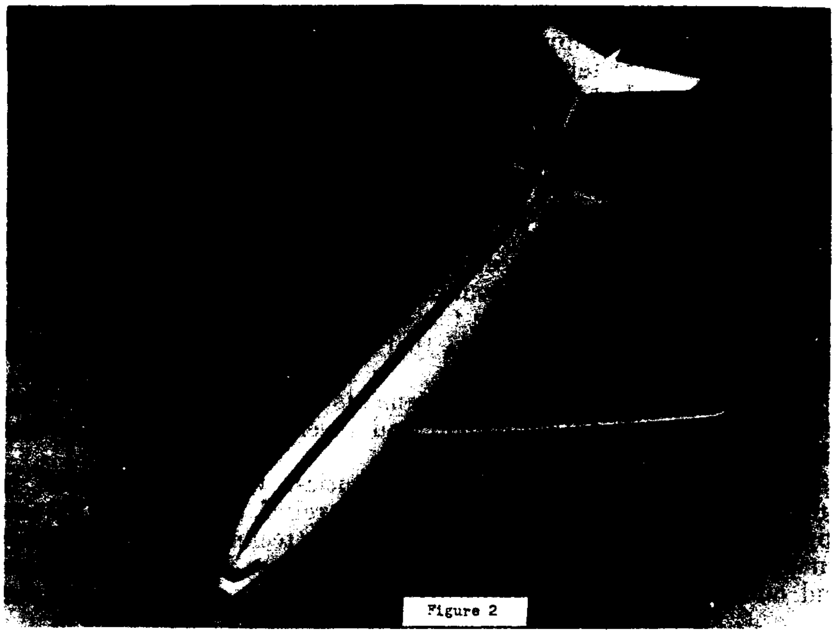


Figure 2

Future transports (fig. 2) will be configured for compatibility with improved terminal-area operations. A recent study has identified conceptual features which include drag brakes for steeper approaches; avionics and displays for precise, efficient control of aircraft movements, high-capacity landing gear for quick runway turnoffs; and several methods of vortex control—for example, outboard nacelle placement—effective at takeoff—and especially scheduled trailing-edge flap deflection and retractable turbulence generators—both effective at landing.

Vortices generated by the wings of large airplanes are a significant factor in terminal-area congestion. At present, they cause us to space aircraft landings a minimum of 3–5 miles apart as a safety precaution. Dramatic progress is being made toward vortex control and dissipation, and we are confident that the separations required for vortex avoidance can be reduced to 1–2 miles. Recent smoke tests in the Langley vortex test facility (fig. 3) provide a visual display of trailing vortices both with and without vortex dissipation devices.

As approach and landing procedures become more precise and tightly scheduled, corresponding improvements will be made in cockpit displays (fig. 4) and automatic landing systems. Augmentation of the pilot's available information and reduction of his workload will improve both energy conservation and safety.

WAKE VORTEX DISSIPATION

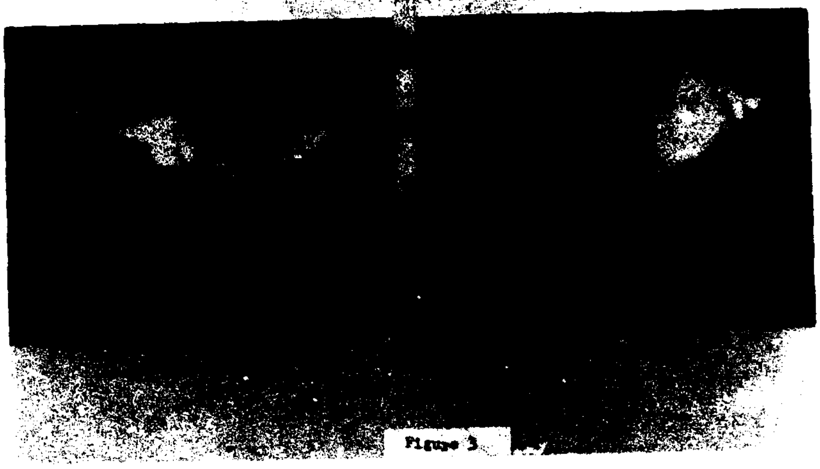


Figure 3

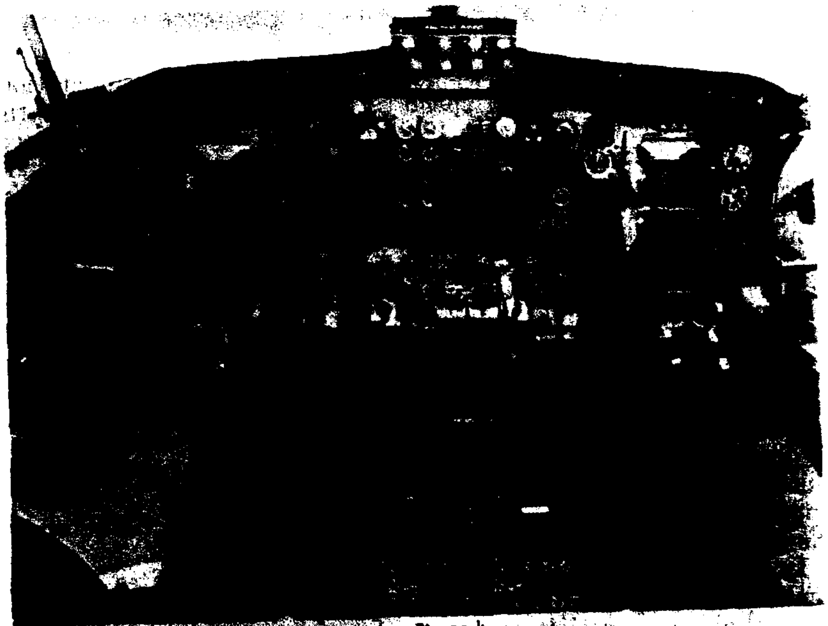


Figure 4

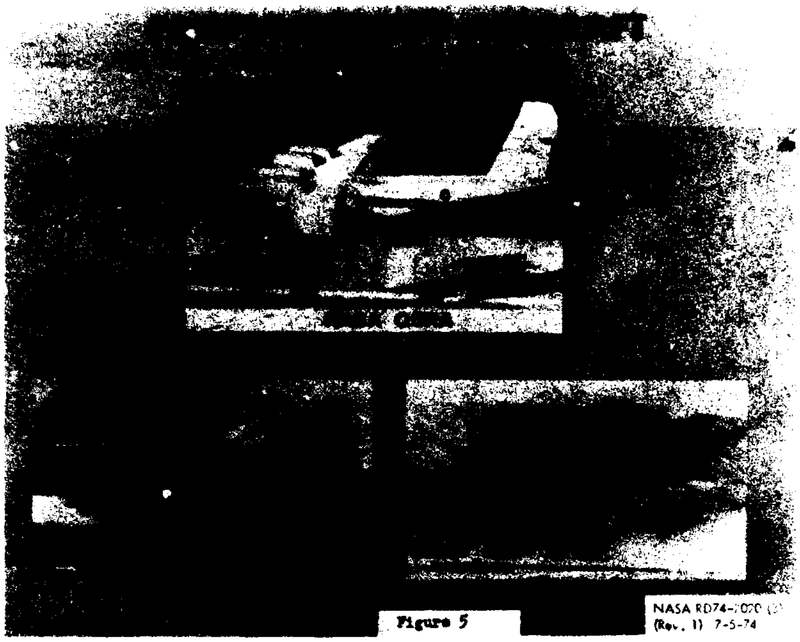


Figure 5

Short-haul aircraft will be particularly benefited by operational improvements because they spend so large a portion of their time operating in the terminal area. The advanced propulsive-lift concepts being pursued for short-haul transports will provide the performance and high maneuverability required for advanced terminal area operations. This capability also permits the use of shorter runways. The combination could eliminate costly delays and fuel waste, and contribute to improvement in overall transport system efficiency. Propulsive-lift concepts are currently being incorporated in the Air Force (AMST) prototype designs and in a NASA research airplane (fig. 5). Results of flight research on these vehicles will provide the basis for design decisions on future military and civil transports.

Vertical take-off and landing aircraft of the future will combine vertical ascent and descent capability with more efficient horizontal flight than is possible with today's helicopters. Apart from considerable improvement possible in the helicopter itself, two concepts appear quite promising for future application—the tilt-rotor and the lift-fan.

In the tilt-rotor concept (fig. 6) the aircraft operates as a conventional helicopter in vertical take-off and landing but attains high-speed flight on wing lift, tilting the large rotors to act as propellers. In the lift-fan concept (fig. 7) gas generators are used to drive vertical-axis fans in the nose, and perhaps also in wing tip pods, for STOL and VTOL operation. Horizontal-axis fans are used for cruise thrust, with nozzles to divert the thrust downward for takeoff and landing. The first applications of VTOL aircraft will probably be military, to satisfy a number of advanced tactical and logistic mis-

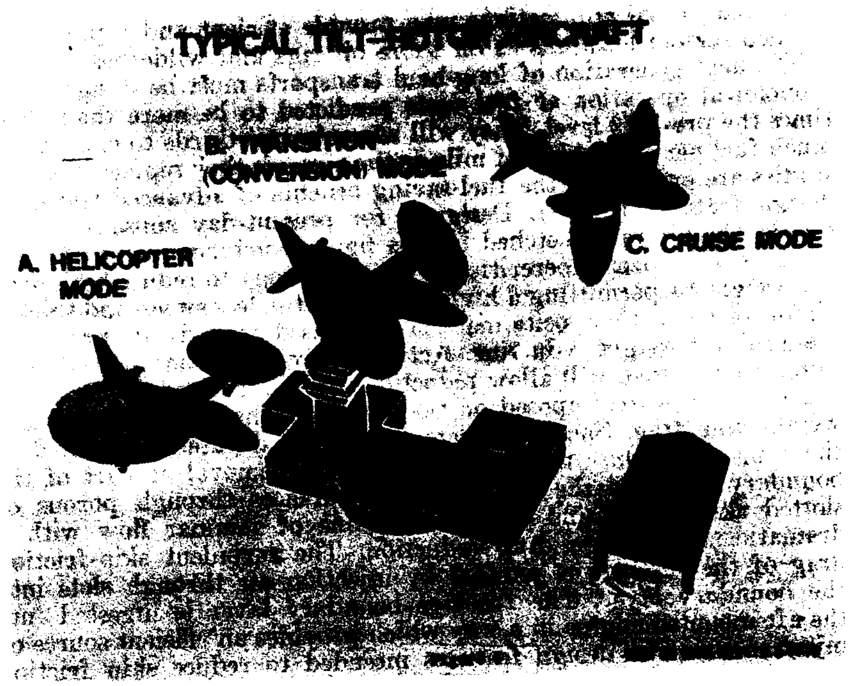

TYPICAL TILT-ROTOR AIRCRAFT
B. TRANSITION
(CONVERSION) MODE
A. HELICOPTER
MODE
C. CRUISE MODE

Figure 7

sion needs. Civil applications may provide efficient and rapid access to such remote locations as off shore oil rigs and wilderness sites.

The next generation of long-haul transports must be designed for economical operation at fuel costs predicted to be more than three times the pre-1973 level. They will use only two-thirds to one-half as much fuel per available seat mile as the aircraft they replace. Current studies are evaluating the fuel-saving benefits of advanced transport design features (fig. 8). Designed for present-day subsonic cruise speeds, the aircraft sketched in this figure combines many of these features. It utilizes supercritical wing technology to reduce both drag and weight by permitting a higher aspect ratio, less sweep and thicker airfoil sections. Composite materials are used extensively, providing a significant weight reduction. Active controls, fast acting and computer coordinated, will allow reductions in inherent aerodynamic stability and in loads imposed on the structure, thereby reducing both weight and drag. Small winglets (or vortex diffusers) mounted at the wing tips reduce the lift-induced drag. Removal of part of the boundary layer on the wing and tail surfaces through porous or slotted skins maintains extensive regions of laminar flow with a dramatic skin-friction drag reduction. The turbulent skin-friction drag of the fuselage is reduced by injecting air through slots into the boundary layer. The fuselage boundary layer is ingested into the aft-mounted engine in a way which provides an efficient source of injection air. The design features intended to reduce skin friction have the potential of great benefits in fuel conservation, but will require considerably more technology development than the other features shown.

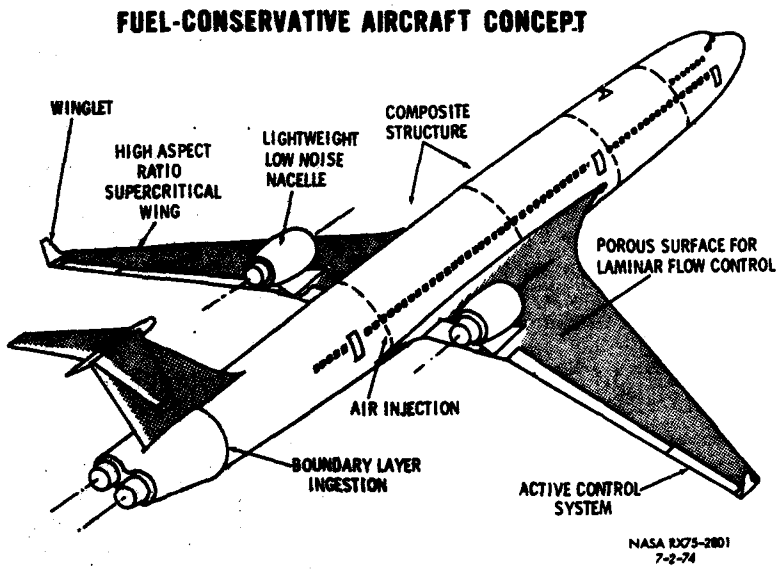


Figure 8

Figure 9

Fuel-conservative engines will incorporate advances in the technology of compressors, turbines, inlets, nozzles, seals, combustors, fuels, and lubricants and some (in later models) will use advanced cycles, including features such as regenerators. A drastic reduction in engine size will accompany the change from current engines (fig. 9, upper engine) to a fuel-conservative, advanced-technology turbofan of conventional cycle (fig. 9, center engine). Installed weight reductions and overall efficiency gains combine to produce an effective fuel-consumption drop of 15 percent. One concept of an energy-conservative advanced-cycle engine (fig. 9, lower engine) incorporates a regenerator, which uses exhaust heat to raise the combustor inlet temperature. This engine is predicted to use 30 percent less fuel than the current-technology turbofan engine. New engines will utilize advanced engine components and will be significantly quieter and cleaner than current engines.

We have a short film illustrating the wake vortex and advanced avionics and information display research which I would like to show now.

The first movie sequence will show the vortices produced by the standard Boeing 747 configuration. Measurements of induced roll are made on the model which follows the 747. The second sequence illustrates the alleviation of the vortex intensity by external devices attached to the model. You will notice the absence of the tightly rolled vortex force.

With continued research there is hope that the vortex problem will be eliminated. The next element in solving the runway capacity problem has to do with reliable and routine all weather operations. This experimental 737 aircraft is a research facility to study this, as well as other problems.

A novel feature of this aircraft is the cabin within the cabin, where instrument pilots may conduct flight evaluations of advanced displays and controls designed specially for all weather situations.

Two examples of the types of advanced displays being studied are shown here. A single display at the top presents integrated altitude data in an improved format. The display at the bottom is, in effect, an active map containing updated position and landmark data.

This scene, a fully automatic landing, illustrates how a pilot-flying with instruments alone can either monitor or control approach, landing, and rollout, using the integrated data concept. The aircraft altitude is displayed digitally in the box in the upper right; a forward facing TV camera is used to superimpose an image of the outside scene on the display. The flight path angle, roll, and drift attitude are indicated by the two wedges in the center of the display. The position of the aircraft with respect to the desired approach path is indicated by the position of the aircraft "symbol" within the "landing guidance" box.

Additional work is needed and planned. For example, a method must be found to display the outside scene in all weather conditions. The research under way will continue to place heavy emphasis on the primary displays needed for pilot confidence in operations independent of weather.

This brief look at aeronautics in the late 20th Century suggests that important changes resulting from advancements in aeronautical technology will make possible considerable improvements in the more familiar forms of military and commercial aircraft. Complementing these evolutionary improvement options, and in some instances competing with them, will be a number of advances along less conventional lines, some of which will be discussed next by Mr. Kayten.

The CHAIRMAN. Thank you very much. That was a fine statement. Mr. Kayten, will you go right on?

Mr. KAYTEN. Mr. Chairman, Senator Goldwater, Mr. Jones has indicated some of the improvements we can expect in conventional aeronautical systems during the 1980's and 1990's. In addition, a number of more radical departures from the conventional systems can be envisioned, some during that same time period, and others as advanced concept options for the more distant future.

One of the primary measures of a transportation system's merit is the product of the payload and the distance it is carried in a given time interval. On the basis of this productivity criterion alone, supersonic transportation appears inevitable, whether or not the first-generation European entries prove economically successful. When an American supersonic transport is undertaken, it will have to offer large advantages over the most advanced subsonic jets, and over the initial and improved versions of the Concorde and the TU-144, in order to compete successfully on the world market. It will also have to overcome the environmental concerns which figured

in cancellation of the original SST prototype program. We believe that the supersonic cruise aircraft research now in progress could lead to a second-generation SST with at least a 100 percent increase in payload capability, a 25 to 30 percent increase in range, and a 25 percent increase in speed relative to the Concorde, with noise levels well below current Federal regulations, and with objectionable engine emission reduced by 90 to 95 percent with respect to present-day engines.

The optimistic predictions are based on several new conceptual approaches which were not far enough along when the first-generation designs were being solidified. These include, for example, the arrow-wing planform and the "blended" configuration (fig. 1) which offer considerable increases in aerodynamic efficiency compared with the more familiar delta shapes (fig. 2) and which now, with new

Figure 1

FIRST GENERATION SUPERSONIC TRANSPORTS

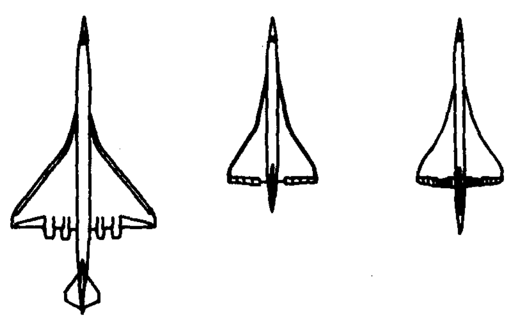


Figure 2

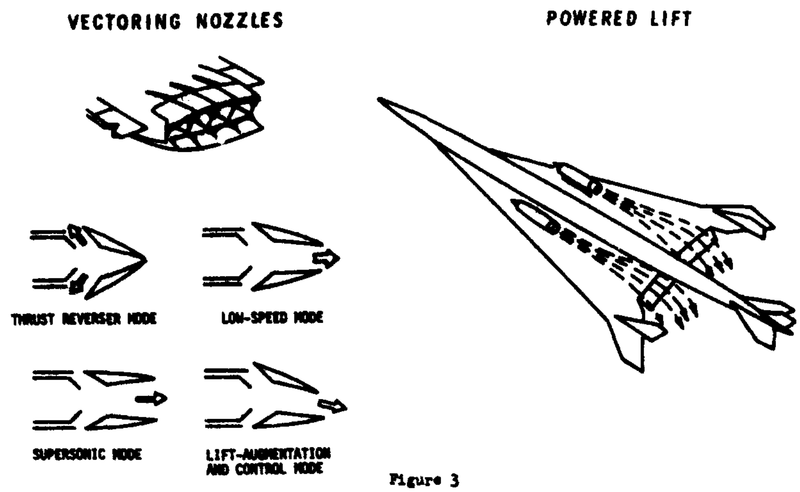


Figure 3

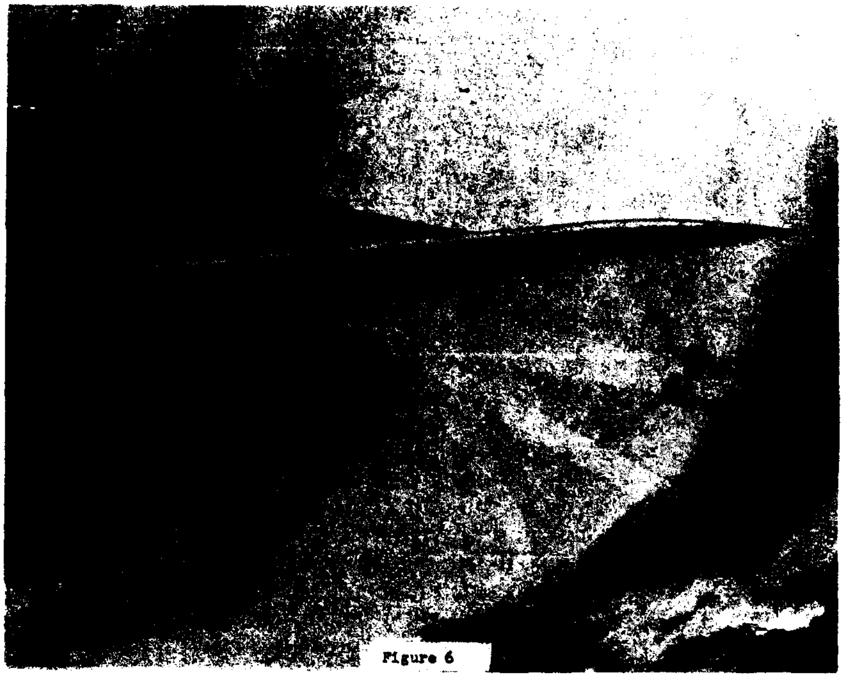
structural concepts, can be designed for practical manufacture. The arrow wing, incidentally, has the additional advantage of spreading the lift over a longer length, reducing sonic boom effects. The advanced supersonic design concepts also include the use of propulsive lift to enhance the wing lift, and the use of a totally new variable-cycle engine (fig. 3). The variable cycle engine is an essential new feature. The concept is somewhat similar to that of the variable-sweep wings used on supersonic combat aircraft. Here the internal engine geometry is altered to vary the engine airflow as a function of flight speed. Operating as a gear shift, the variable cycle optimizes efficiency for both low-speed and high-speed flight, and permits low-noise take-off and landing. Lastly, the new configurations will gain additional performance through the weight savings achieved by use of the active controls concept. In the supersonic applications, the active controls may include vectored thrust as well as aerodynamic control surfaces.

For certain civil or military missions, flight at very low supersonic speeds, with no sonic boom effects at all, may prove necessary or highly desirable. The oblique-wing concept (fig. 4) offers an interesting option for such applications, providing both drag and weight benefits relative to symmetrically swept wings. In low-speed flight, the wing is rotated to operate as a conventional unswept wing with its inherent low-speed performance and safety advantages. The oblique-wing is also being studied to determine whether it offers significant benefits in subsonic applications.

Apart from the fuel conservation concepts discussed by Mr. Jones and the efforts toward synthetic hydrocarbon fuels, the use of liquid hydrogen, or possibly liquid methane, as an alternate fuel is being considered for both subsonic and supersonic aircraft. Depending on the cost and energy required to produce them, the liquified glass

Figure 4

Figure 5



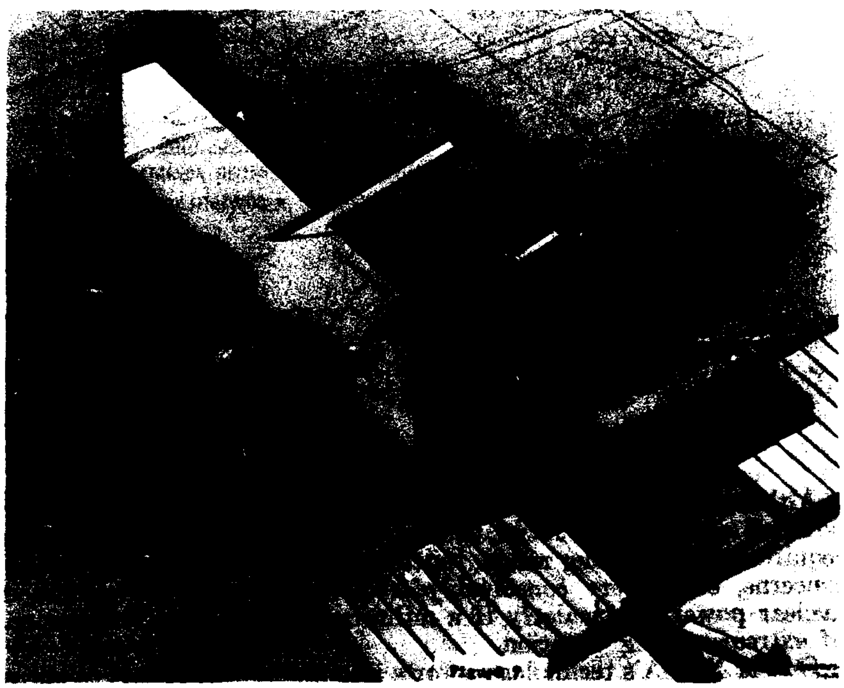
could be of interest as a means of reducing dependence on petroleum and other fossil fuel sources. If the hydrogen can be carried internally, the subsonic hydrogen transport (fig. 5) will not appear much different from a conventional design, and the high energy content of the hydrogen will actually result in some weight and performance advantages. If the external-pod arrangement is selected for safety reasons, the performance will be somewhat degraded. In a supersonic design (fig. 6), the hydrogen configuration again appears conventional, and the performance improvement is even more significant. From the standpoint of the airplane and engine design, the cryogenic fuel concept appears entirely feasible. The more formidable technology problems lie in the system support areas of economical hydrogen production liquefaction, distribution, storage, and handling.

Perhaps the greatest air transport growth in the future will occur in the air freight field where extremely large demand is expected toward the end of the century. Several of the advanced concepts now being studied are directed at the cargo requirement, looking at advanced ground handling concepts as well as advanced cargo vehicle concepts.

The projected demand growth, the large size and weight of some of the anticipated cargo units, the handling considerations, and the advantages of scale all suggest the eventual development of very large air vehicles that will dwarf the largest wide-body transports flying today. The size alone will present a number of technology problems, even if the vehicles are relatively conventional airplanes.

If systems and economic studies indicate that unconventional aircraft, or surface-effect machines, or airships offer attractive alternatives, either for general transportation or for important unique applications, the required technology preparation may be still more extensive. For example, preliminary study indicates that one potentially attractive and productive airship concept may be a totally new form of vehicle, a hybrid in which the lift developed from buoyancy is supplemented by aerodynamic lift, or propulsive lift, or both. Our studies of the cargo requirement, and the various alternative approaches to meeting it, include consideration of lighter-than-air and semibuoyant vehicles as well as conventional aircraft.

The large cargo airplane may carry most of its load and its fuel in the wing rather than in the body (figs. 7 and 8). This flexibility in load distribution is one of the benefits of large size, and permits major savings in structural weight, since the distributed load balances the aerodynamic lift forces on the wing. The result is a potential payload increase on the order of 50 percent, with a corresponding decrease in operating cost and fuel per ton-mile. Other advanced concepts being considered (fig. 9) include: coupled aircraft in which the efficiency and distributed span-loading of the large wing are obtained by in-flight combination of individual smaller units which may operate from independent termnials; tandem aircraft in which the large loads are carried in the body but supported by two wings; and large, conventional low-speed airplanes in which advanced technology is deliberately avoided in favor of design simplicity and low manufacturing cost.



LOAD DISTRIBUTIONS FOR CARGO AIRCRAFT

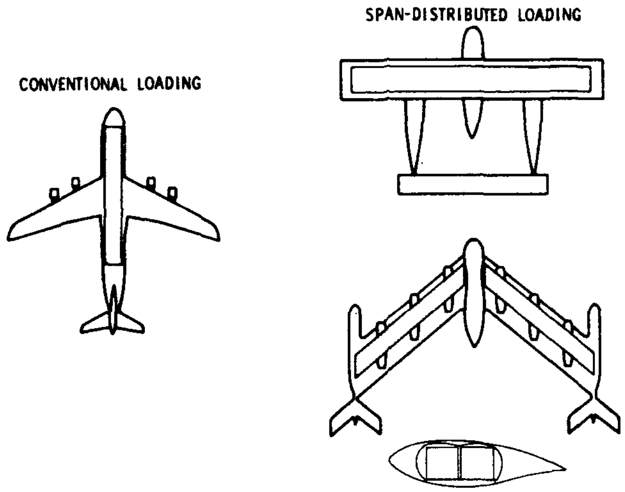


Figure 8

CARGO AIRCRAFT DESIGN FOR SPECIAL APPLICATIONS

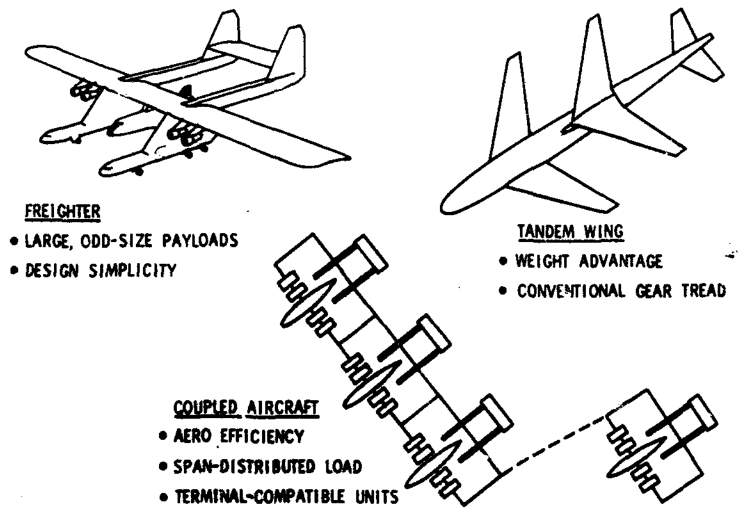


Figure 9

Although no active effort is currently under way toward nuclear-powered aircraft, the trend toward very large size, large payload requirements, and long range, together with the fossil fuel shortage concerns, could very conceivably lead to a revival of interest in nuclear power, particularly if a military need emerges for missions of extremely long duration.

One of NASA's technology efforts in support of military requirements is directed at developing concepts for substantial improvements in advanced fighter maneuverability (fig. 10). We have been perfecting the techniques of remotely piloted research vehicles, to

ADVANCED FIGHTER CONCEPTS

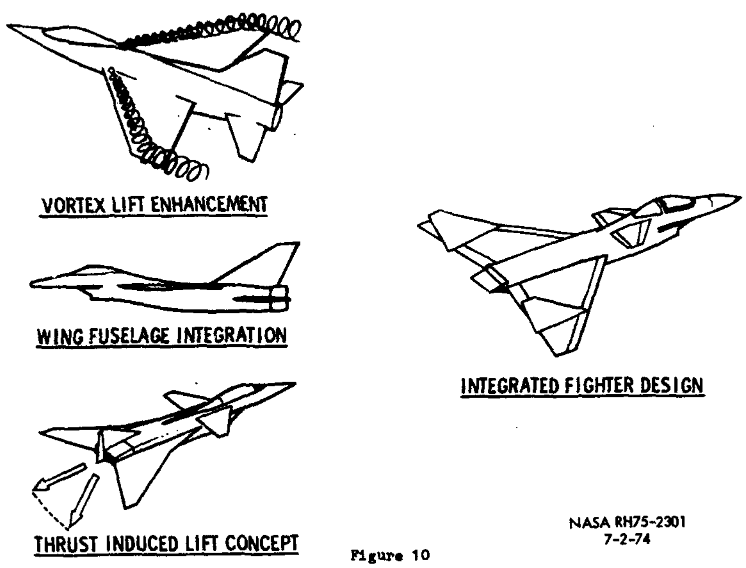


Figure 10

minimize cost and risk in flight testing selected high maneuverability design concepts. The military services are experimenting with remotely piloted vehicles—RPV's—for missions such as battlefield surveillance. It is possible that RPV's may in the future be found useful for specialized civil applications such as monitoring of severe storms, forest fire detection, fire fighting, disaster assistance, and remote area deliveries.

The hypersonic transport may be a follow-on or perhaps even an alternative to second-generation supersonic flight. Operating at three times the speed of Concorde—or about eight times the speed of today's jet transports—and capable of very long ranges, the hypersonic transport could be of interest in an era of increased East-West and African trade. Hypersonic transports would operate at extremely high altitudes and use liquid hydrogen fuel.

At first glance, the hypersonic airplane (fig. 11) looks quite similar to a supersonic vehicle. Actually, there are some major differences. The airplane is powered not by a conventional turbojet or turbofan engine, but by a supersonic-combustion ramjet (fig. 12) intergrated into the structure. Because of the very high flight speeds, the structure must be cooled by circulating liquid, depending on the large cooling capacity of the liquid hydrogen to remove the heat. Hypersonic research engine tests have been conducted successfully in the laboratory; a possible flight research program to further the development of the hypersonic cruise flight concepts is currently being considered jointly by NASA and the Air Force.

In the much more distant future, there exists the possibility of semiglobal, or suborbital, rocket-propelled transport which could evolve concurrently with further advances in space transportation.

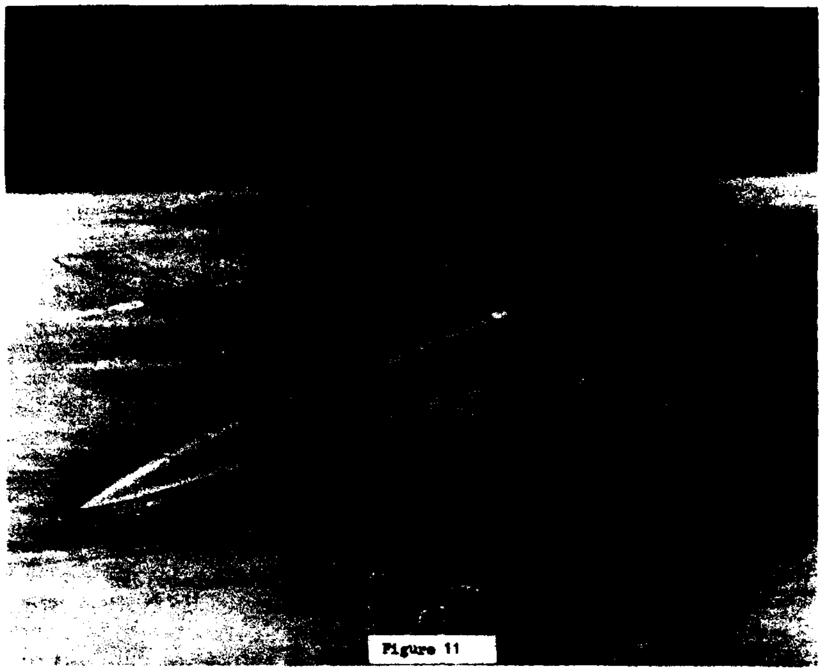


Figure 11

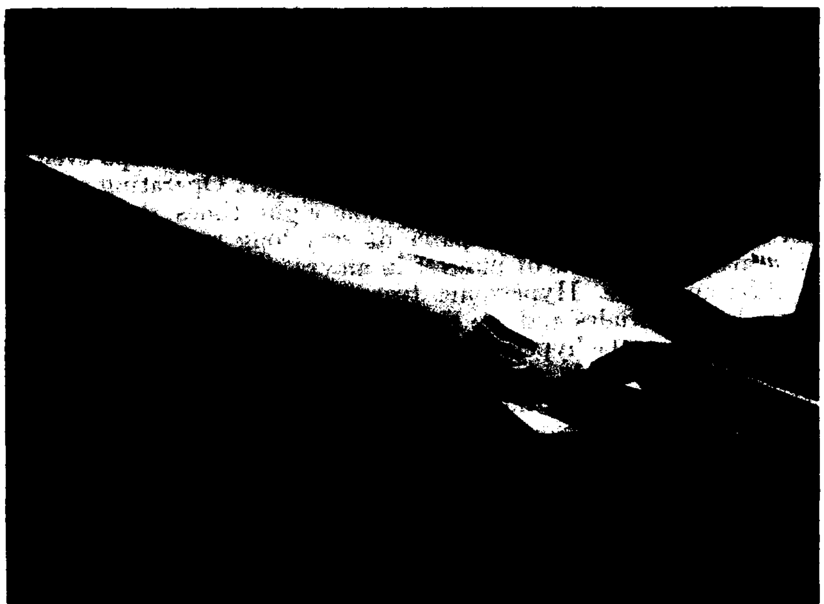


Figure 12

We have reviewed only some of the potential new developments in aeronautics. We have covered them only sketchily, and have not discussed any of the research and technology programs which will make these advances possible. We will be pleased to provide any additional information you may require.

The CHAIRMAN. Thank you very much, Mr. Kayten, for the glimpse you, Mr. Jones, and Dr. Fletcher have given us. It is stimulating and pricks our curiosity as to what further we can be moving onto.

I wonder, Mr. Fletcher, if you could have more funding for aeronautics, what do you see as the most pressing need or the greatest opportunity for rapid advance?

Dr. FLETCHER. Well, it is hard to point to one particular program as needing funding. I would like to turn to my associates in a minute, but I would say that I feel a little uneasy about the lack of funding for this variable cycle engine that Mr. Kayten was talking about for possible supersonic application. I think that development of that engine will not only be useful for possible supersonic transports in the future but may be useful in other applications and we are not really spending enough money in that area.

Mr. KAYTEN. Yes sir. The variable cycle engine is the one key item. At the moment we cannot even predict when the Nation would be ready to make a decision on proceeding with supersonic transport development. With about 5 years of research efforts on the variable cycle engine we believe that we would have that information in hand and be on our way if the decision is positive.

The CHAIRMAN. How much effort are you able to put on it now, on the variable cycle engine?

Mr. KAYTEN. At the moment we are working on component research toward the variable cycle engine which is probably appropriate for maybe this year or next year. Beyond that it would require a significant increase to really proceed with variable cycle engine research.

The CHAIRMAN. And about 5 years out you think it ought to be in a position where we could be seriously considering its utilization in supersonic aircraft?

Mr. KAYTEN. Yes, sir.

The CHAIRMAN. Dr. Fletcher, as you know, it was this committee that recommended the Civil Aviation Research and Development or CARD policy study several years ago. Can you tell us what the status is of your efforts to implement the recommendations of the CARD study?

Mr. JONES. Well, the recommendations of the CARD study dealt primarily with the noise and congestion problems of our transportation system. Since the time of that study we have emphasized research in those areas in our program and certainly that emphasis remains. We will continue to do that.

More recently, of course, there has been much concern over the energy conservation aspects of aviation and that has to be taken into account with the pollution and noise research because in some areas the requirements are not compatible and compromise must be made.

So the direct answer to your question is that we continue to emphasize the noise and congestion problems as was noted in the testimony.

The CHAIRMAN. That is on-going now on a regular basis?

Mr. JONES. Yes. That is an essential part of our research program.

The CHAIRMAN. I would like to turn to my colleague, Senator Goldwater. I may want to come back later with another question or two.

Senator GOLDWATER. Mr. Jones, referring to your vortex supressors in figure 2 (p. 8), you did not fully explain the effect of the plunger. That is all I can call it. That is what it looks like. Near the wing tip of each wing. What does that do?

Mr. JONES. There is an example of that shown on the model in front of me. It is essentially a turbulence generator which introduces turbulence into the stream at the location of the vortex and that turbulence tends to break up the continuity of the vortex. Those are envisioned to be used in the landing approach. They would not be appropriate for takeoff because of the high drag that they introduce. But the high drag in the landing approach may well be compatible with steeper approach concepts in the landing approach.

Senator GOLDWATER. Yes, but you had vortex on takeoff. Would the placing of the engine near the wing tip tend to overcome the lesser vortex that is developed on takeoff? I know it is not a traffic problem but we have had some accidents on takeoff following jet aircraft too closely by conventional light aircraft.

Mr. JONES. Well, the one advantage in takeoff is that aircraft are dispersing rather than converging, but the aspect we show here is the outboard placement as you point out—placement of the outboard engine near the wing tip so that the energy which it contributes tends to disperse the vortex and avoid the concentrated vortex core some distance behind the aircraft.

Senator GOLDWATER. Just as a matter of information, in your vortex research what is the maximum distance that the vortex has been of sufficient force to cause problems behind preceding aircraft? I ask that because one night I ran into vortex problems nearly 10 miles behind a 707 and it actually started to roll me. How far back will that——

Mr. JONES. I would think that is about the limit. We have encountered significant disturbances 7 to 10 miles behind large transport aircraft.

Senator GOLDWATER. Thank you.

Now, relative to the oblique wing, that is a very interesting concept. I wish you could go into it a little more. It would be a conventional wing on takeoff and landing?

Mr. KAYTEN. That is right. It would be unswept for takeoff and landing.

Dr. FLETCHER. It is mostly useful, Senator Goldwater, in the region just beyond sonic, about Mach 1.2 or thereabouts.

Senator GOLDWATER. Well, could you explain the aerodynamic advantages in placing it in the oblique position? I can see some problems being accentuated if we confine it in a conventional wing such as in a turn, the higher wing goes faster than the lower wing creating

varying lift problems. Would not this happen to a more marked degree with the oblique wing in that position?

Mr. KAYTEN. It does not seem to, Senator. The actual advantage is largely one of structural weight rather than aerodynamic—in a much more simple hinge and pivot mechanism. There is an aerodynamic advantage and perhaps Mr. Jones would want to explain that. It has to do with the reduced drag forces on the oblique wing.

Mr. JONES. Well, the aerodynamic advantage is that it is effectively a higher aspect ratio wing than a conventional swept wing where both panels of the wing are swept back, comparing wings of the same span. There is a higher degree of aerodynamic efficiency in the yawed wing.

Senator GOLDWATER. What happens to the turbulence on the wing? Does it travel straight back or does it tend to go along when the wing is in that position?

Mr. JONES. Well, the boundary layers flow very close to the surface, tends to follow back along the wing but the general flow over the wing does not.

Senator GOLDWATER. You have done wind tunnel tests on this, have you not?

Mr. JONES. Yes. We have a number of wind tunnel tests. Boeing has made studies for us of the possibility of application of this concept to a transport aircraft.

Dr. FLETCHER. Senator, we have also flown small models of that skewed wing exhibit, to study some of the stability and control aspects of it. It seems to behave reasonably well so far.

Senator GOLDWATER. It is a two-position set up or can this be varied?

Mr. JONES. It could be varied. Primarily I think it would be flown in two positions, unswept for low speed and highly swept for the high speed cruise.

Senator GOLDWATER. Does this have any effect on the sonic boom problem?

Mr. KAYTEN. The configuration itself does not but the speed at which it would be flying is selected so that there would be no sonic boom effects reaching the ground.

Senator GOLDWATER. You got into hydrogen fuel. How far away are we from the practical use of hydrogen?

Mr. KAYTEN. We think, Senator, with respect to the aircraft problems the technology could be ready probably in the mid-1980's. However, the hydrogen economy aspects, the production and distribution and the ground support systems, and above all the economical availability of the hydrogen fuel, that seems to be considerably farther, possibly at the very end of the century. We do not believe that we would go in a civil application to hydrogen use for aircraft alone. Aircraft would use hydrogen if the rest of the world were using hydrogen in large quantities.

Senator GOLDWATER. Well, it is a much stronger fuel, is it not? Say per cubic foot of fuel would you not get more power from the hydrogen than you would out of any conventional fuel?

Mr. KAYTEN. You get considerably more energy per pound. The volume is actually larger. Yes sir, it is about something on the order

of three times the energy per pound that we have in the hydrocarbon fuels. Then there is a compensating loss because of the volume and the installation, things that go with it. It still ends up a net gain in applications depending, of course, on what the manufacture and liquefaction costs are.

Senator GOLDWATER. Now, I wonder if you could give us a short explanation of the variable cycle engine. I can understand a reciprocating engine but when you get into the fan type engine, what cycle are you varying?

Mr. KAYTEN. The thing primarily being varied is the quantity of air flow through the engine and the—effectively the by-pass ratio, and in one simple model which we started to bring up but it was a little too small to visualize, we actually have just a two-position series of tubes, if you will, one permitting a larger passage of air, the other one a smaller one, and by rotation we switch from one to the other. There are a variety of different ways of accomplishing this. But basically it is to permit more bypass air at one speed range than in another.

Senator GOLDWATER. Do we not do that now in the SR-71 engine? If that is the cycle that you are talking about, the cycle of air, is that not the secret of the SR-71 engine, the control of air?

Mr. KAYTEN. I think, Senator, what we are doing there is—you mean the variation of the inlet size?

Senator GOLDWATER. Yes.

Mr. KAYTEN. I think that—it does not quite do the same thing. It does not alter the ratio of bypass to straight through air. It alters the total air. I believe that is the difference.

Senator GOLDWATER. Well, do we not do that to some extent in the bypass engine today?

Mr. KAYTEN. We do it at a fixed ratio and that is why the high bypass ratio is excellent for low speed takeoff thrust, for low noise and so on. In supersonic flight, it is a loss. Ideally what you would like to have is a straight jet in supersonic flight and a high bypass ratio engine for takeoff and landing, and these mechanisms for jockeying the amount of air in effect provide that for us. This is all in the very early conceptual stage at the moment.

Senator GOLDWATER. Are there any papers available on what you have done so far? Let's say is there a paper available on the basic concept?

Mr. KAYTEN. Yes sir. We can provide that.

Senator GOLDWATER. I would like to have one just for my own use.

[Material requested follows:]

The terminology "variable cycle" as applied to engines has come to be associated with those engines which operate as turbofan engines at subsonic speed and as straight or after-burning turbojets at supersonic speed. Variable cycle engine types include, but are not limited to: Single valve variable cycle engines; mixed mission integrated propulsion systems; variable stream control engines; and dual valve variable cycle engines.

The characteristics of all of these types of variable cycle engines are that they move large amounts of air at relatively low velocity at subsonic speeds for low noise and good specific fuel consumption, and relatively small amounts of air at high velocity at supersonic speeds for optimum cruise specific fuel consumption.

A single valve variable cycle engine would use a valve or flow diverter between dual fans by which some of the front fan air would be bypassed around the second fan and additional auxiliary inlet air provided to the second fan for subsonic operation, but, for supersonic operation, all intake air would pass through front and rear fans and the compressor stages.

A mixed mission integrated propulsion system would use three turbojet engines in a single pod where, for subsonic operation, some of the main inlet air is bypassed in ducts around two outboard engines with the main stream through the compressor, burners, turbine, and nozzle of the middle engine. Auxiliary inlet air is also ducted through the compressors, etc., of the outboard engines in the pod. For supersonic operation, the auxiliary inlets are closed and main inlet air feeds all three engines. The total system thus operates as a turbofan at subsonic speeds and a turbojet at supersonic speeds.

A variable stream control engine is a variation on a duct heating turbofan in which, for subsonic operation, the duct heater is not lit, while for supersonic speeds, it is lit. Such an engine would also contain variable fan, compressor, and turbine geometry.

A dual valve variable cycle engine being studied intensively is shown in the enclosed chart. At subsonic speeds, this engine would operate in a high-bypass mode (upper part of chart). In this mode, the intake air is split to pass through (a) the front fan, then the rear fan, the high compressor, the burners, the high and low turbines and the second low turbine as in a straight turbojet, and (b) the front fan and then through an auxiliary nozzle similar to the operation of a bypass jet. Since additional bypass air is needed, an auxiliary inlet is also opened which carries the additional air around the compressor and turbines and discharges it at the primary nozzle. This bypass air may be given additional energy for acceleration modes by use of the duct heaters if required. For the supersonic cruise mode (lower part of chart) the auxiliary inlets and nozzles are closed and the intake air is split to pass through (a) the compressor, the burners, and the high and low turbines to be discharged through the rear flow diverter valve into the outer duct without passing through the second low turbine, and (b) the duct heater and the rear flow diverter valve to power the second low turbine. In the supersonic cruise mode, the engine is in essence a dual turbojet with the intake airflow matched to the requirements of the compressor/burner/high and low turbine path and the fan/duct heater/second low turbine path.

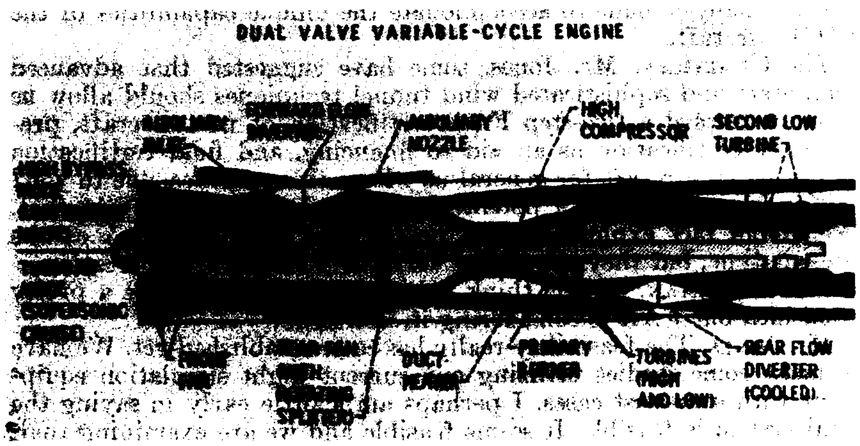


FIGURE 18

The CHAIRMAN. Thank you. Mr. Jones, NASA has been working steadily for many years on the STOL aircraft but the civil STOL always seems to be just around the corner. Are we getting any closer to a widespread use of STOL or is it still a long way off?

Mr. JONES. Well, I believe the use of STOL in the transportation system will be an evolutionary process because it requires a complete

38-266 O - 74 - 3

system to be totally effective. I think the development of the Air Force AMST prototype aircraft and the testing done with the NASA research airplane, pictures of which were shown here, will go a long way toward defining capabilities that can be built into STOL aircraft. The AMST aircraft, of course, do not have the constraints on them that are placed on an aircraft designed for civil operation, particularly in the area of noise.

Dr. FLETCHER. Could I clarify that statement? We use terms sometimes that are technical and not always understood. When we say systems, we mean the airplane, the airport, the landing system, and the traffic control system that takes the STOL from one place to another. Just changing the plane to a STOL does not give you all the advantages of a STOL system. You really need to change the way airports are designed and you need to change the traffic control system, the whole works, along with it to get full advantage.

What Mr. Jones is saying, I think, is that the technology for all of these things is available. For the airplane, we are doing it, but the whole system is a very expensive and a slow changing kind of thing. What he is saying is it will gradually happen, not suddenly happen.

The CHAIRMAN. Is there not a great demand for STOL; isn't there quite a bit of pressure for it?

Mr. JONES. Well, I think there is no lack of demand from the standpoint of adding to the efficiency of our transportation system but the cost of installing a STOL system, and I use that term along the lines defined by Dr. Fletcher, is significant and that is why I believe it will happen as an evolutionary process.

As the aircraft becomes available, it will be used initially within the existing airports and as the system totally develops, then there will be changes made to accommodate the unique capabilities of the STOL aircraft.

The CHAIRMAN. Mr. Jones, some have suggested that advanced computers and sophisticated wind tunnel techniques should allow us to move toward a two-step FAA certification of new aircraft, preliminary certification as an aid to financing, and final certification of the actual aircraft for general use. Does this seem feasible to you?

Mr. JONES. There is a potential there, I believe, to do just that. We are in fact exploring those possibilities with the FAA at the present time, but they are in the very early stages of exploration.

The CHAIRMAN. So you think it is feasible and would be a pretty good idea but FAA is considering it, is that it?

Mr. JONES. The feasibility really has to be established yet. We have to make some studies utilizing our current flight simulation equipment with some test cases. I perhaps am a little early in saying the total system is feasible. It seems feasible and we are examining that. We would like to establish the feasibility. Of course, certification is the FAA's concern and anyway in which we can help them with NASA technology, we will certainly standby to do it.

The CHAIRMAN. Well, certification is a bit costly, is it not? How much does it cost to certify a 747?

Mr. JONES. I am afraid, Mr. Chairman, I cannot answer that question.

The CHAIRMAN. Well, my information is it is quite a long and complicated process and takes a vast amount of money; I just wondered if there could be a simplification and if the two-step certification might lead to simplification.

Mr. JONES. Well, certainly it is a costly process and anything we can do with the technology that NASA works with to assist the FAA and the industry in reducing those costs should be looked at and we are doing that.

The CHAIRMAN. Senator Metzenbaum, do you have any questions?

Senator METZENBAUM. I had an Interior Committee hearing at the same time as this one so I was a little late. I have just one question on the usage of STOL in the total system aspect, could you explain what it requires at the landing field? You talked about three areas other than the equipment itself and I was a bit curious because I could not quite envision the problem.

Dr. FLETCHER. I'll defer to our expert on airports. Let us try Jerry Kayten. Jerry is the expert in this area.

Mr. KAYTEN. The STOL airplane, Senator, is really not so much a short runway operation as a low speed flight capability which enables you to maneuver very tightly and utilize the minimum of air space and keep noise off the community and things like that.

One of the things you need to be able to utilize that capability to the fullest extent is the, oh, things like the microwave landing system which provides information to the pilot and which he can use in guiding the airplane, and particularly under instrument conditions. The things that we would really like to do with these propulsive lift airplanes is to separate them from the conventional traffic and use them to relieve the congestion that was built in a few years ago and has slacked off now, which is one reason for the slackening in the apparent demand. But to do this, it simply means that you want to use additional airports or additional runways and that means just prosaic things like terminal buildings and baggage handling and traffic. So it is not a sophisticated system that is required in some cases. It is just——

Senator METZENBAUM. It is a simpler system. You would use a simpler kind of a runway, a runway which would not be as long.

Mr. KAYTEN. That is right.

Senator METZENBAUM. And therefore I am wondering why, in answer to the Chairman's question—you talk about the fact you needed a special kind of airport. It would seem to me that most airports that I can recollect have long runways but often times have shorter runways that are not used.

Mr. KAYTEN. Yes, you could use the airports but you would not get the benefit for which they would be developed and the cost just would not warrant it.

Senator METZENBAUM. How much runway do you need on an average STOL takeoff and landing?

Mr. KAYTEN. It could be as low as 2,000. It is more costly to design for that, more likely 3,000 feet would be about average.

Senator METZENBAUM. One point, there was a good deal of publicity about STOL being totally vertical on takeoff. Is that just a nice conversation topic?

Mr. KAYTEN. No, sir. We would call that VTOL and Mr. Jones showed some pictures. We are working towards that, too. But it is a little further away and a little more costly.

Senator METZENBAUM. Thank you.

Dr. FLETCHER. Senator Metzenbaum, could I add one other thought? One of the easiest illustrations of a STOL airport would be a 3,000 foot runway placed in the middle of the East River, lets say, right along side of Manhattan. You could do that with STOL and you would really gain a big advantage if you came up with something like that. I am not proposing to do it but you could do that and then relieve a lot of the traffic that lands out at Kennedy International and it would be a lot easier to get into work from there.

That is just an illustration of something that could be done with STOL in order to take real advantage of the possibility of a short runway.

Another possibility you already mentioned, use short pieces of existing airports. But then you have got to figure out the traffic, how to take advantage of that short piece so it does not get mixed up with the traffic using the longer runways.

All of these things have to be put together in a national system and that is being considered now but it is not being done.

Senator METZENBAUM. Thank you.

The CHAIRMAN. Thank you. Senator Goldwater, you have an additional question?

Senator GOLDWATER. Would you not say that the landing and takeoff of helicopters at the conventional airports presents somewhat the same kind of a problem that you are talking about? I mean they have not really solved that yet.

Dr. FLETCHER. No question about it. If helicopter traffic grows any more it is going to really congest the airports that we have; and I do not know, but I suspect that helicopter traffic is partly limited by the other traffic patterns. Is that a proper statement?

Mr. KAYTEN. It is but not as much as STOL traffic is limited, because the STOL is still a normal flying machine and the controllers bring them in in normal approaches and intermixes them, whereas the helicopter they will allow to come in on taxi strips and in the hanger areas and things like that. They are a little less reluctant to mix them in with conventional airplanes. If there were a lot more of them as Dr. Fletcher says, they probably would get a little more concerned.

Senator GOLDWATER. That model behind you, with the variable altitude engines, we have one of those flying now, made in Canada? Not exactly like that. It is not the large rotor type blade but——

Mr. KAYTEN. That rotates the entire wing and——

Senator GOLDWATER. Yes.

Mr. KAYTEN [continuing]. And it is more of a propeller driven airplane like the CX–142 was, whereas this is more of a conventional helicopter. It is a different approach to the same general concept, yes.

Senator GOLDWATER. And Sikorsky came out with a contra-rotating rotor for helicopter use and, in fact, I think they built a prototype to eliminate all of the torque problems. Have you had anything to do with that?

Mr. KAYTEN. I did not see the article but we have been testing with Sikorsky, their so-called ABC concept and I think that is about what that is.

Senator GOLDWATER. I have a few more questions, Mr. Chairman. Does the United States now possess the technology to build an economically attractive SST?

Dr. FLETCHER. That is really a tough question. My guess is—if you forgot about all the environmental issues—it would be possible, but just barely so. My recommendation would not be to start an SST right now; but to develop the technology necessary to build an economical and environmentally acceptable SST. I would defer that decision to later in the decade and work intensively on the technology so indeed when we made the decision, if we made the decision, we would have an economically, and as pointed out in the testimony, a much more viable airplane than either the Concorde or the Soviet planes.

Senator GOLDWATER. You answered my next question.

Has NASA studied the economics of a hypersonic transport?

Mr. KAYTEN. I do not believe we have gone very deeply into the economics. We have been working the technology both for possible transport and for military use. I think the economics of the hypersonic transport—I do not really believe we would have a sound basis for analyzing that and it would depend really on missions and markets that we can not yet visualize. We know it would be feasible technically. We do not know it would be desirable economically.

Senator GOLDWATER. Remember in 1946 hearing Hall Hibbard of Lockheed talk about the Mach 4 transport flight. I think everybody in the room thought he was off his rocker.

Mr. Kayten, do you believe lighter-than-air vehicles can help the nation's future transportation needs?

Mr. KAYTEN. Well, we are going into some fairly extensive studies to develop a better answer to that. I believe there are certain unique requirements for which lighter-than-air can do things that nothing else can do. What we do not know yet is the extent of the requirement, whether or not it would justify development, and one of the reasons we are making the kind of studies that we are entering into now is that the lighter-than-air we believe starts to look more attractive when you introduce new technology. New technology means new effort and additional cost and we are trying to be sure enough of our ground so that if we enter into a technology development effort we are doing it because we know the demand and justifications are there.

The answer to your question is, yes. I believe that lighter-than-air can help. What we want to find out is where it can help and what applications and what type of vehicles and what technology we could provide that would help with the development.

Senator GOLDWATER. Again, Mr. Kayten, has NASA looked at the hybrid proposed by the Aereon Corporation of Princeton, New Jersey?

Mr. KAYTEN. Yes sir. We conducted some studies of our own on a hybrid which is very similar to the Aereon general concept some years ago. The Goodyear people proposed one like it and this was one of the conceptual approaches that turned some of us on about the potential of lighter-than-air or semilighter-than-air. The hybrid does offer higher payload capability, higher speed, higher altitude, and better ground handling possibilities and a number of the things that would make an airship more feasible. We have asked in the studies that we are about to undertake that that be one of the types of configurations given particular study by the study contract.

Senator GOLDWATER. As you know, as you gentlemen have demonstrated, what really surprised me is the varied interest in lighter-than-air in this country. I just made a few casual remarks a few moments ago about lighter-than-air and I am already a member of about 5 associations. In fact, there is one being built not too far from my home in Arizona and a number of others that are undergoing development. So I hope you keep up with it.

One last question, Mr. Kayten. Has NASA studied the circulation control rotor based on the Coanda effect?

Mr. KAYTEN. I believe we have some people working with the Navy Department in testing of that concept at the NSRDC facility, and we provided some technical assistance. I do not recall whether we actually did any of our own testing. We did—I think, when Mr. Jones was still out at Ames, we tested something somewhat similar in one of these cooperative programs with one of the French helicopter companies but it was not quite the same thing. We are aware of it and our people have been working with the Navy people but I believe the development you are talking about has been worked primarily by the Naval Air Systems Command, if it is the one I think it is.

Senator GOLDWATER. They are coming on today. I have not seen it. It has been over a year, and I have not kept up with what progress is being made. I wondered if NASA had their hands in that particular project.

Mr. JONES. The tests conducted at the Ames Research Center were on a jet flap rotor which actually used a jet exhaust at the trailing edge of the blade.

Senator GOLDWATER. There was some experimentation, I believe, too, of that same effect replacing our alternating wing flaps, is that correct?

Mr. KAYTEN. The upper-surface blown wing approach to propulsive lift essentially uses that principle.

Senator GOLDWATER. Gentlemen, that is all I have, Mr. Chairman.

The CHAIRMAN. Thank you. The Senator from Oklahoma, do you have any questions?

Senator BARTLETT. I have no questions, Mr. Chairman.

The CHAIRMAN. Thank you very much, gentlemen. We do appreciate it, Dr. Fletcher and Mr. Jones and Mr. Kayten. It was an interesting presentation and we appreciate being updated a little. We would like to have you back and get updated some more very soon. Thank you.

[Prepared statements follow:]

PREPARED STATEMENT OF B. K. HOLLOWAY, ACTING ASSOCIATE ADMINISTRATOR FOR AERONAUTICS AND SPACE TECHNOLOGY, NASA

I welcome the opportunity to discuss with this Committee some of the advanced aeronautical concepts which may affect our lives in the foreseeable future. I have with me Mr. J. Lloyd Jones, my Deputy for Aeronautics, and Mr. Gerald G. Kayten, Director of our Study and Analysis Office.

In the 70-year history of powered flight, continuing research has made possible some remarkable improvements in the efficiency, economy, comfort, and safety of flight. Research has enabled the U.S. to maintain world leadership in both civil and military aviation—a position now being threatened by increasingly serious foreign competition. The statistics shown in Figure 1 illustrate the importance of the high-technology, highly competitive field of air transportation.

NASA and its predecessor, NACA, have contributed a major share of the aeronautical research foundation upon which the nation's military and civil aviation pre-eminence has been built. In light of the results, the cost of this research has been quite modest. The investments involved in a single major aeronautical venture such as the Boeing 747 or an equivalent military program can easily exceed 3 billion dollars. The aeronautical exports for a single year, as shown in Figure 1, can also exceed this figure—which is considerably greater than the total spent on aeronautical research by NASA and NACA during the entire 60 years of their combined existence.

A vigorous national program of aeronautical research and technology must be maintained in view of the pressures of international competition and military preparedness, and the vital concerns for energy conservation and environmental protection in meeting the nation's long-term air transportation needs.

NASA's aeronautical programs provide the essential technology foundations, and contain the seeds from which we, the military services, and the industry evolve a variety of advanced concepts. These concepts constitute options for eventual development. Among them are several which will greatly alter the character of future aviation systems, but it is virtually impossible at this time to predict which will actually be developed and produced. This will, of course, depend on the demonstration of technical feasibility, but it will depend also on a combination of economic, social, military, and political considerations which will determine the willingness and ability to finance the undertaking.

Even in the case of a clear technical breakthrough, it is difficult to judge where and how a new concept will be applied. The NASA supercritical wing, for example, was originally conceived and tested as a means of achieving a 15–20% increase in jet transport cruise speed, to approximately Mach 1, the speed of sound (Figure 2). Technical feasibility was demonstrated successfully, but although the higher-speed performance is being considered for specialized combat aircraft and business jet applications, it has not yet been found sufficiently beneficial economically to justify its general adoption for commercial transportation. In the meantime, however, a completely secondary benefit of the supercritical wing concept has emerged as an extremely important feature and is currently being utilized in several advanced military and commercial transport designs. In this alternate application, which was demonstrated in a joint NASA/Navy flight research program, the wing is considerably thicker than that required for near-sonic speed. Instead of the speed advantage, the thicker supercritical wing permits considerable savings in weight, cost, and—most significantly—fuel (Figure 3). Mr. Jones will discuss this and other fuel-conservation concepts in his statement.

Although we cannot predict with confidence where the advanced concepts will lead, we can postulate where they may lead—and we think the prospects are quite exciting. In the remainder of this half hour we will review some of the more interesting concepts and the uses to which they may be put. Since you will be receiving separate military testimony, we will place most of our emphasis on potential civil applications. Mr. Jones will cover the nearer-term future, in which significant improvements in the familiar forms of subsonic air transportation appear possible. Mr. Kayten will address the more speculative and farther out future possibilities. We will then be pleased to answer your questions or to provide additional information not included in our statements.

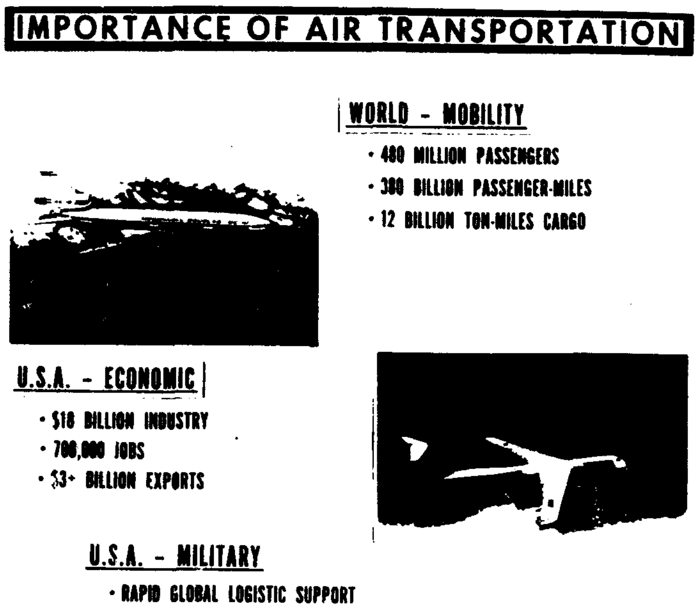


Figure 1

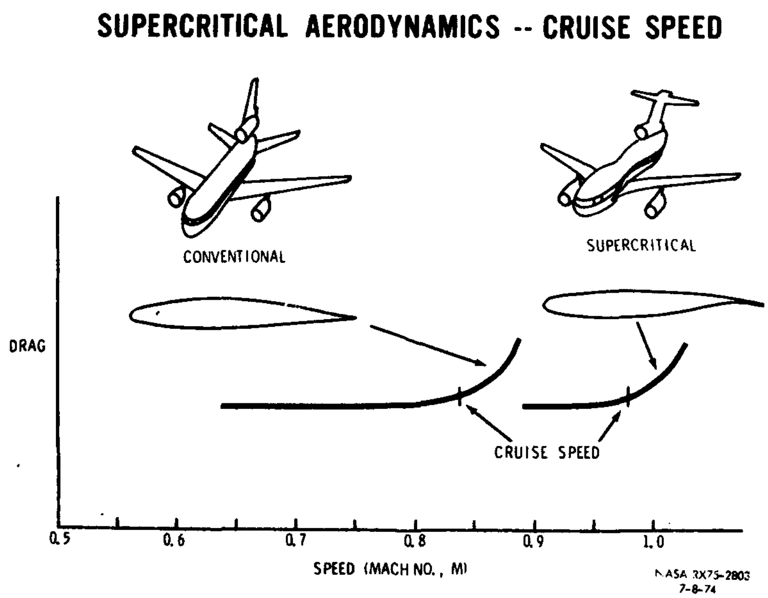
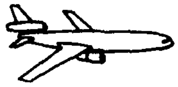
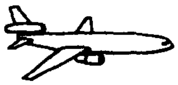


Figure 2

SUPERCRITICAL WING---FUEL SAVINGS



CONVENTIONAL (M=.8)



SUPERCRITICAL (M=.9)

FUEL CONSUMPTION

200 AIRPLANE FLEET	1.6 BILLION GALLONS PER YEAR	1.36 BILLION GALLONS PER YEAR

ANNUAL FUEL SAVINGS : 240 MILLION GALLONS

NASA RX75-2802
7-2-74

Figure 3

Prepared Statement of J. Lloyd Jones, Deputy Associate Administrator (Aeronautics), OAST, NASA

The major trends in aviation over the next two decades will be influenced strongly by commitments already made by the aircraft operators and by technology developments now under way. These developments, particularly those undertaken in response to pressing needs such as energy conservation and environmental improvements, will lead to significant changes in the relatively near-term future.

Toward the end of the century, a new generation of civil transports will be in operation. Most of the wide-body jets of today will have been replaced in trunk-line service, and a greatly expanded and diversified airline market will be served. Despite the temporary setbacks being experienced by the airlines, it is still predicted that total passenger miles flown per year may be three or more times the current traffic, even in the face of somewhat increased fares and improvements in alternate transportation modes.

Air transportation will continue to be economical, environmentally acceptable and socially beneficial. Aircraft engines, which constitute only a minor factor in pollution, will become even cleaner. Noise impact on a community will be drastically reduced from that of past and present jet aircraft. Above all, the aircraft will be fuel-conservative, an essential feature because the energy shortage and fuel costs will continue to be issues of great importance. These improvements will be achieved as a result of technology advances on which research is now in progress.

During this time period, advancements are expected in three general areas: operations, short-haul and special-purpose aircraft, and long-haul transports.

A major element in future aeronautics, which contributes to fuel economy, noise reduction, congestion relief, and safety, is a new approach to operations. Some of the techniques (Fig. 1, see page 7) include steep, curved approaches; reduced separation distances; fewer holds in flight and on the ground; and, improved all weather operations. The two-segment approach now being introduced in limited operations is the forerunner of these advanced techniques. In later developments, advanced avionics and active controls will permit routine maneuvers which are beyond the capability of an unaided pilot, especially in exploiting the unique terminal-area characteristics of STOL and VTOL aircraft.

Future transports (Fig. 2, see p. 8) will be configured for compatibility with improved terminal-area operations. A recent study has identified conceptual features which include drag brakes for steeper approaches; avionics and displays for precise, efficient control of aircraft movements, high-capacity landing gear for quick runway turn-offs; and several methods of vortex control—for example, outboard nacelle placement (effective at take-off), specially scheduled trailing-edge flap deflection and retractable turbulence generators (both effective at landing).

Vortices generated by the wings of large airplanes, which have been described as miniature horizontal tornadoes, are a significant factor in terminal-area congestion. At present, they cause us to space aircraft landings a minimum of 3–5 miles apart as a safety precaution. Good progress is being made toward vortex control and dissipation, and we are confident that the separations required for vortex avoidance can be reduced to 1–2 miles. Recent smoke tests in the Langley vortex test facility (Fig. 3, see p. 9) provide a visual display of trailing vortices with and without vortex dissipation devices.

As approach and landing procedures become more precise and tightly scheduled, corresponding improvements will be made in cockpit displays (Fig. 4, see p. 9) and automatic landing systems. Augmentation of the pilot's available information and reduction of his workload will improve both energy conservation and safety.

Short-haul aircraft will be particularly benefited by operational improvements because they spend so large a portion of their time operating in the terminal area. The advanced propulsive-lift concepts being pursued for short-haul transports will provide the performance and high maneuverability required for low-speed, steep, precise, quiet operations in the terminal area. This capability also permits the use of shorter runways. The combination could eliminate costly delays and fuel waste, and contribute to improvement in overall transport system efficiency. Propulsive-lift concepts are currently being incorporated in the Air Force YC–14 and YC–15 (AMST) prototype designs and in a NASA research airplane (Fig 5, see p. 10). Results of flight research on these vehicles will provide the basis for design decisions on future military aircraft and civil transports.

Vertical Take-Off and Landing (VTOL) aircraft of the future will combine vertical ascent and descent capability with more efficient horizontal flight than is possible with today's helicopters. Apart from considerable improvement possible in the helicopter itself, two concepts appear quite promising for future application—the tilt-rotor and the lift-fan.

In the tilt-rotor concept (Fig. 6, see p. 11), the aircraft operates as a conventional helicopter in vertical take-off and landing but attains high-speed flight on wing lift, tilting the large rotos to act as propellers. In the lift-fan concept (Fig. 7, see p. 11), gas generators are used to drive vertical-axis fans in the nose, and perhaps also in wing tip pods, for STOL and VTOL operation. Horizontal-axis fans are used for cruise thrust, with nozzles to divert the thrust downward for takeoff and landing. The first applications of VTOL aircraft will probably be military, to satisfy a number of advanced tactical and logistic mission needs. Civil applications may provide efficient and rapid access to such remote locations as off shore oil rigs and wilderness sites.

The next generation of long-haul transports must be designed for economical operation at fuel costs predicted to be more than three times the pre-1973 level. They will use only one-third to one-half as much fuel per available seat mile as the aircraft they replace. Current studies are evaluating the fuel-saving benefits of advanced transport design features (Fig. 8, see pp. 12, 37). Designed for present-day subsonic cruise speeds (Mach No. = 0.8), the aircraft sketched in this figure combines many of these features. It utilizes supercritical wing technology to reduce both drag and weight by permitting a higher aspect ratio, less sweep and thicker airfoil sections. Composite materials are used extensively, providing a significant weight reduction. Active controls, fast acting and computer coordinated, will allow reductions in inherent aerodynamic stability and in loads imposed on the structure, thereby reducing both weight and drag. Small winglets (or vortex diffusers) mounted at the wing tips reduce the lift-induced drag. Removal of part of the boundary layer on the wing and tail surfaces through porous or slotted skins maintains extensive regions of laminar flow with a dramatic skin-friction drag reduction. The turbulent skin-friction drag of the fuselage is reduced by injecting air through slots into the boundary layer. The fuselage boundary layer is ingested into the aft-mounted engine in

FUEL-CONSERVATIVE AIRCRAFT CONCEPT

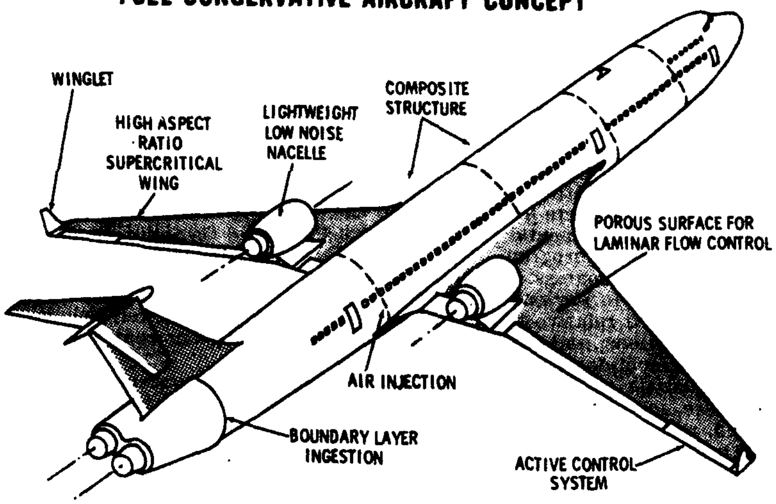


Figure 8

a way which provides an efficient source of injection air. The design features intended to reduce skin friction have the potential of great benefits in fuel conservation, but will require considerably more technology development than the other features shown.

Fuel-conservative engines will incorporate advances in the technology of compressors, turbines, inlets, nozzles, seals, combustors, fuels and lubricants and some (in later models) will use advanced cycles, including features such as regenerators. A drastic reduction in engine size will accompany the change from current engines (Figure 9, see p. 13 upper engine) to a fuel-conservative, advanced-technology turbofan of conventional cycle (Figure 9, center engine). Installed weight reductions and overall efficiency gains combine to produce an effective fuel-consumption drop of 15 percent. One concept of an energy-conservative advanced-cycle engine (Figure 9, see p. 13 lower engine) incorporates a regenerator, which uses exhaust heat to raise the combustor inlet temperature. This engine is predicted to use 30 percent less fuel than the current-technology turbofan engine. New engines will utilize advanced engine components and will be significantly quieter and cleaner than current engines.

One important concept affecting the evolution of all future, highly-efficient aircraft is the use of computer-aided design methods, utilizing the powerful computer capabilities now coming into operation (Figure 10). Combined with advanced wind tunnel facilities, these advanced analytical techniques permit extensive early exploration and optimization of design alternatives, reduced trial-and-error in development, closer approaches to design criteria and margins and, consequently, reduced cost.

This brief look at aeronautics in the late 20th Century suggests that important changes resulting from advancements in aeronautical technology will make possible considerable improvements in the more familiar forms of military and commercial aircraft. Complementing these evolutionary improvement options, and in some instances competing with them, will be a number of advances along less conventional lines, some of which will be discussed next by Mr. Kayten.

PREPARED STATEMENT OF GERALD G. KAYTEN, DIRECTOR, STUDY AND ANALYSIS OFFICE (OAST), NASA

As Mr. Jones has indicated, we can expect considerable improvement in conventional air transportation systems during the 1980's and 1990's. In addition, a number of more radical departures from the conventional systems can be envisioned. Some of these advanced concepts could be developed concurrently with

the improved traditional types; others are probably much farther into the future. All of them are credible options which are considered to be technically feasible.

One of the primary measures of a transportation system's merit is the product of the payload and the distance it is carried in a given time interval. On the basis of this productivity criterion alone, supersonic transportation appears inevitable, whether or not the first-generation European entries prove economically successful. When development of an American supersonic transport is undertaken, it will have to offer large advantages over the most advanced subsonic jets, and over the initial and improved versions of the Concorde and the TU-144, in order to compete successfully on the world market. It will also have to overcome the environmental concerns which figured in cancellation of the original SST prototype program. We believe that the supersonic cruise aircraft research now in progress could lead to a second-generation SST with at least a 100% increase in payload capability, a 25–30% increase in range, and a 25% increase in speed relative to the Concorde, with noise levels well below current federal regulations, and with objectionable engine emissions reducer by 90–95% relative to present-day engines.

The optimistic predictions are based on several new conceptual approaches which were not far enough along when the first-generation designs were being solidified, and which still require considerable work to assure technology readiness. These include, for example, the arrow-wing planform and the "blended" configuration (Figure 1, see p. 15) which offer considerable increases in aerodynamic efficiency compared with the more familiar delta shapes (Figure 2, see p. 15). Interest in these refined aerodynamic shapes has been spurred by new structural concepts which have increased our confidence that the configurations can be designed for practical manufacture. The arrow wing, incidentally, has the additional advantage of spreading the lift over a longer length and thereby reducing sonic boom effects. The advanced supersonic design concepts also include the use of propulsive lift to enhance the wing lift for low-speed performance improvement and noise reduction (Figure 3, see p. 16), and the use of a totally new variable cycle engine. The variable cycle engine, which is still in the early study stage and requires extensive technical development, is an essential new feature. The concept is somewhat similar to that of the variable-sweep wings used on supersonic combat aircraft. Here the internal engine geometry, rather than the wing geometry, is altered to vary the engine airflow as a function of flight speed. Operating in a sense as a gear shift, the variable cycle permits effective low-noise operation for takeoff and landing while still maintaining high efficiency for supersonic cruise. Lastly, the new configurations will gain additional performance through the weight savings achieved by use of the active controls concept. In the supersonic applications, the active control may include vectored thrust as well as aerodynamic control surfaces.

Despite the anticipated sonic boom reduction, the advanced supersonic configurations will still probably be restricted to subsonic flight over land. For certain civil or military missions, "slightly" supersonic speeds, producing no sonic boom effects at all, may prove necessary or highly desirable. The oblique-wing concept (Figure 4, see p. 17), offers an interesting option for such applications, providing both drag and weight benefits relative to symmetrically swept wings designed for the same requirements. In low-speed flight, the wing is rotated to operate as a conventional unswept wing with its inherent low-speed performance and safety advantages. The oblique-wing is also being studied to determine whether it offers significant benefits in subsonic applications.

Apart from the fuel conservation concepts discussed by Mr. Jones, NASA and the military services are exploring the use of synthetic hydrocarbon fuels. In addition, the use of liquid hydrogen, or possibly liquid methane, as an alternate fuel is being considered for both subsonic and supersonic aircraft. Depending on the cost and energy required to produce them, the liquified gases could be of interest as a means of reducing dependence on petroleum and other fossil fuel sources. If the hydrogen can be carried internally, the subsonic hydrogen-fueled transport (Figure 5, see p. 17) will not appear much different from a conventional hydrocarbon-fueled design, and the high energy content of the hydrogen will actually result in some weight and performance advantages. If the external-pod arrangement is selected for safety reasons, the performance will be somewhat degraded. In a supersonic design (Figure 6, see p. 18), the configuration again appears conventional, and the performance improvement is even more

significant. Substantial technical effort is required to assure adequate thermal protection and strength in lightweight fuel tanks, but from the standpoint of the airplane and engine design, the cryogenic fuel concepts appear entirely feasible. The more formidable technology problems lie in the system support areas of economical hydrogen production, liquefaction, distribution, storage, and handling.

Perhaps the greatest air transport growth in the future will occur in the air freight field, where even the most conservative projections indicate a tremendous increase in demand toward the end of the century. This increase will necessitate considerable new development, and several of the advanced concepts now being studied are directed at the cargo requirement. The advanced cargo vehicle concepts are influenced by the need for compatibility with advanced handling concepts in containerization, automation, and computerized control which will serve advanced surface systems as well as air modes.

The projected demand growth, the large size and weight of some of the anticipated cargo units, the handling considerations, and the advantages of scale all suggest the eventual development of very large air vehicles that will dwarf the largest wide-body transports flying today. The size alone will present a number of technology problems, even if the vehicles are relatively conventional airplanes. If systems and economic studies indicate that unconventional aircraft, or surface-effect machines, or airships offer attractive alternatives for either general transportation or important unique applications, the required technology preparation may be still more extensive. For example, preliminary study indicates that one potentially attractive and productive airship concept may be a totally new form of vehicle, a hybrid in which the lift developed from buoyancy is supplemented by aerodynamic lift, or propulsive lift, or both. To assess the technology needs NASA, DOT, and the military services are conducting studies of the cargo requirement and the various alternative approaches to meeting it. The NASA studies include consideration of lighter-than-air and semi-buoyant vehicles as well as conventional aircraft.

The large cargo aircraft may carry most of its load and its fuel in the wing rather than in the body (Figures 7 & 8, see pp. 19, 20). This flexibility in load distribution is one of the benefits of large size, and permits major savings in structural weight since the distributed load balances the aerodynamic lift forces on the wing. The result is a potential payload increase on the order of 50 percent, with a corresponding decrease in operating cost and fuel per ton-mile. Other advanced concepts being considered (Figure 9, see p. 20) include: coupled aircraft in which the efficiency and distributed span-loading of the large wing are obtained by in-flight combination of individual smaller units which may operate from independent terminals; tandem aircraft in which the large loads are carried in the body but supported by two wings; and large, conventional, low-speed airplanes in which advanced technology is deliberately avoided in favor of design simplicity and low manufacturing cost.

Although no active effort is currently under way toward nuclear-powered aircraft, the trend toward very large size, large payload requirements, and long range, together with the fossil fuel shortage concerns, could very conceivably lead to a revival of interest in nuclear power, particularly if a military need emerges for missions of extremely long durations.

As General Holloway stated, our emphasis in this statement has been primarily on civil air transportation concepts. Much of NASA's effort, of course, is devoted to generating technology in support of military requirements. One of these efforts is directed at developing concepts for substantial improvements in advanced fighter maneuverability (Figure 10, see p. 21). We have been working toward perfecting the techniques of remotely piloted research vehicles (RPRV's), to minimize cost and risk in flight testing selected high combat maneuverability design concepts. At the same time, the military services are experimenting with remotely piloted vehicles (RPV's) for missions such as battlefield surveillance. It is possible that RPV's may in the future be found useful for specialized civil applications such as monitoring of severe storms, forest fire detection, fire fighting, disaster assistance and remote area deliveries.

The hypersonic transport can be envisioned as a follow-on or perhaps even an alternative to the second-generation supersonic flight. Operating at three times the speed of Concorde—or about eight times the speed of today's jet transports—and capable of very long ranges, the hypersonic transport could be of interest in an era of increased East-West and African trade. Hypersonic transports

would operate at extremely high altitudes and use liquid hydrogen fuel. With respect to environmental considerations, the altitude increase significantly reduces sonic boom effects on the ground and, although the hydrogen fuel may present a water vapor problem, it contains no hydrocarbon pollutants.

At first glance, the hypersonic airplane (Figure 11, see p. 22) looks quite similar to a supersonic vehicle. Actually, there are some major differences which account both for the spectacular performance and the technological risk. The airplane is powered not by a conventional turbojet or turbofan engine, but by a supersonic-combustion ramjet (Figure 12, see p. 22) integrated into the structure. Because of the very high flight speeds, the structure must be cooled by circulating liquid through tubes embedded in the external skin, depending on the large cooling capacity of the liquid hydrogen to remove the heat. Hypersonic research engine tests have been conducted successfully in the laboratory; a possible flight research program to further the development of the hypersonic cruise flight concepts is currently being considered jointly by NASA and the Air Force.

In the much more distant future, there exists the possibility of semi-global, or sub-orbital, rocket-propelled transports which could evolve concurrently with further advances in space transportation—that is, with eventual development of a fully reusable successor to the Space Shuttle system.

In this brief session we have reviewed only some of the potential new developments in aeronautics. We have covered them only sketchily, and we have not discussed any of the research and technology programs which will make these advances possible. We will be pleased to provide additional pertinent information as required.

The CHAIRMAN. We will now hear from representatives of the Navy, Vice Admiral W. J. Moran, Director of Navy Research, Development, Test and Evaluation, in the Office of the Chief of Naval Operations; accompanied by Mr. William Koven, Director of Advanced Aircraft Development of the Naval Air Systems Command.

We are pleased to have you before us, Admiral Moran and Mr. Koven, and look forward very much to your testimony.

[Biographies of Admiral Moran and Mr. William Koven follow:]

BIOGRAPHY OF VICE ADMIRAL J. MORAN, UNITED STATES NAVY

William Joseph Moran was born in Burlingame, California, on July 20, 1919, son of William J. and Anna Field Moran. He attended Santa Rosa Junior College and the University of Nevada, graduating from the latter with the degree of Bachelor of Arts. He began naval service on February 19, 1941, had pre-flight training at the Naval Reserve Aviation Base, Oakland, California, and flight training at the Naval Air Station, Corpus Christi, Texas. Designated a Naval Aviator, he was commissioned Ensign in the U.S. Naval Reserve on December 24, 1941, shortly after the outbreak of World War II that month. Through subsequent advancement and his transfer from the Naval Reserve to the U.S. Navy in 1946, he attained the rank of Vice Admiral, to date from December 1, 1972.

Assigned from January through March 1942 to the Advanced Carrier Training Group, San Diego, California, he had instruction with a similar group at Norfolk, Virginia, the next two months and in June reported to Fighting Squadron Three, based on the USS *Hornet* (CVA–8). He later served with Fighting Squadron Seventy-Two, based on that carrier and subsequently on the USS *Nassau* (CVE 16). He was awarded the Distinguished Flying Cross, a Gold Star in lieu of a second similar award, and two Air Medals for outstanding service with that squadron.

The first DFC was for "extraordinary achievement in aerial combat as a Pilot of the USS *Hornet* Air Group during action against enemy Japanese forces in the Solomon Islands Area, October 13, 1942 . . ." The second DFC was awarded for completing his twentieth mission during the Battle of Santa Cruz and in the vicinity of Guadalcanal, Solomon Islands, from October 14 to 26, 1942; and the Air Medals were for five missions each during operations against the Japanese enemy forces in the Solomon Islands from September 18 to October 5, 1942, and from February 6 to 20, 1943, respectively.

Upon his return to the United States in April 1943, he was ordered to the Naval Auxiliary Air Station, Green Cove Springs, Florida, as an Instructor.

He remained there until August 1944, then returned to the Pacific Area to serve throughout the latter period of the war as Operations Officer and Executive Officer of Fighting Squadron Ten and Bombing-Fighting Squadron Ten, based on the USS *Intrepid* (CV-11). For extraordinary achievement while serving with these squadrons, he was awarded Gold Stars in lieu of another Distinguished Flying Cross and two additional Air Medals.

Relieved of active duty on December 27, 1945, he remained in inactive status in the Naval Reserve until his appointment in the regular Navy, then reported in January 1947 to Commander Carrier Division Seventeen. He served for four months as Assistant Operations Officer on that Staff, and during the period June 1947 to December 1948 was Assistant Operations Officer on the Staff of Commander Fleet Air, Alameda. He was a student at the General Line School, Monterey, California, from January through December 1949, after which, from January 1950 until February 1952 he served as Operations Officer and Assistant Experimental Officer at the Naval Ordnance Test Station, Inyokern, California.

When detached he became Project Officer, and later served as Operations Officer of Composite Squadron Three, and from February 1953 until July 1954 was Commanding Officer of Fighter Suqadron Twenty-three, based on the USS *Essex* (CVA-9) and operating in the Korean Area. Upon his return to the United States he was ordered to the Naval War College, Newport, Rhode Island, where he completed the Command and Staff Course in June 1955. That month he was assigned to the Naval Ordnance Test Station, China Lake, California, where he remained for more than three years as Assistant Experimental Officer.

From October 1958 until November 1959 he served as Weapons Officer on the Staff of Commander Naval Air Force, Atlantic, and for fourteen months thereafter was Executive Officer of the USS *Essex* (CVA-9). In February 1961 he began a tour of duty as Naval Aide to the Assistant Secretary of the Navy (Research and Development), Navy Department, Washington, D.C.

In August 1964 he reported for instruction at the National War College, Washington, D.C., and after completing the course there in June 1965, assumed command of the USS *Rainier* (AE-5). In August 1967 he became Commander Antisubmarine Warfare Group Three and "for exceptionally meritorious service from June to October 1968 . . ." in that capacity was awarded the Legion of Merit.

In November 1968 he reported as Director of the Navy Space Program Division, Office of the Chief of Naval Operations, Navy Department. As such, he provided for the exploitation of space systems to furnish solutions to many operational problems and advanced the system in the fields of satellite communications. ocean surveillance satellite navigation and meteorology. He was awarded a Gold Star in lieu of the Second Legion of Merit "for exceptionally meritorious service . . ." in that assignment. In October 1970 he became Commander of the Naval Weapons Center, China Lake, California and in December 1972 assumed duty as Director of Research, Development, Test and Evaluation, Office of the Chief of Naval Operations, Navy Department.

In addition to the Legion of Merit with Gold Star, the Distinguished Flying Cross with two Gold Stars, and the Air Medal with three Gold Stars, Vice Admiral Moran has the Presidential Unit Citation Ribbon for the award to the First Marine Division (Reinforced) for World War II service (Guadalcanal) and the Meritorious Unit Commendation awarded the USS *Bennington*. He also has the American Defense Service Medal; American Campaign Medal; Asiatic-Pacific Campaign Medal with four operation stars; World War II Victory Medal; Navy Occupation Service Medal, Asia Clasp; China Service Medal; National Defense Service Medal with bronze star; Korean Service Medal; United National Service Medal and the Vietnam Service Medal. He also has the Vietnamese Navy Distinguished Service Order Second Class and the Republic of Vietnam Campaign Medal with Device.

Vice Admiral Moran and his wife, the former Ruth Eleanor Nelson of St. Croix Fall, Wisconsin, have three daughters, Margaret E., Christine R. and Mary Louise Moran. His official residence is 1340 Nixon Avenue, Reno, Nevada.

BIOGRAPHY OF WILLIAM KOVEN (NAVAL AIR SYSTEMS COMMAND)

Mr. Koven received a Bachelor of Science Degree in Aeronautical Engineering in 1944 and has taken numerous postgraduate courses in aeronautical engineering as well as in management. His early experience was obtained at the Langley

Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics (NACA) where he was engaged in research work on aircraft flying qualities and swept wing aerodynamics from 1944–1948. He left NACA in 1948 to join the aerodynamic staff of the CAA from whence he joined the Navy Department's Bureau of Aeronautics in 1949. He has been with the Bureau of Aeronautics and its successors, the Bureau of Naval Weapons and the Naval Air Systems Command since 1949 except for a short stint in 1955 as aerodynamic consultant to the USAF Directorate of Flight Safety at Norton Air Force Base. His recent positions with the Naval Air Systems Command include Chief of Aerodynamics, Technology Administrator for Aerodynamics, Structures and Materials, and Director, Office of Advanced Aircraft Development.

Mr. Koven has served on numerous Technical Committees of the American Institute of Aeronautics and Astronautics and the American Helicopter Society. In the past he served on a number of NACA/NASA research advisory subcommittees and presently is a member of the NASA Research and Technology Advisory Committee on Aeronautics. He is also the Navy member of the Flight Mechanics Panel of AGARD. His awards include the Navy Superior Civilian Service Award and a special commendation from the FAA for his services as Associate Technical Director of the first Supersonic Transport Evaluation.

STATEMENT OF VICE ADM. W. J. MORAN, USN DIRECTOR, NAVY RESEARCH, DEVELOPMENT, TEST AND EVALUATION, ACCOMPANIED BY THE FOLLOWING NAVAL AIR SYSTEMS COMMAND PERSONNEL: WILLIAM KOVEN, DIRECTOR, ADVANCED AIRCRAFT DEVELOPMENT; CAPT. A. A. SCHAUFELBERGER, USN, PROJECT MANAGER, THRUST AUGMENTED WING, V/STOL; T. F. KEARNS, TECHNOLOGY ADMINISTRATOR, AERODYNAMICS, STRUCTURES AND MATERIAL; E. A. LICHMAN, ASSISTANT TECHNOLOGY ADMINISTRATOR FOR ADVANCED AIR BREATHING ENGINES; R. G. PERKINS, AIRCRAFT CONCEPTS MANAGER AND R. F. SIEWERT, ASSISTANT TECHNOLOGY ADMINISTRATOR FOR AERODYNAMICS

Admiral MORAN. Good morning Mr. Chairman.

The CHAIRMAN. Good morning. You may proceed, sir.

Admiral MORAN. It is a pleasure to be here. We appreciate the opportunity to tell this committee about some of the concepts and technologies currently under exploration or development in the Navy today. They are efforts that we hope will provide us with more capable aircraft tomorrow.

Current Navy aircraft possess remarkable capabilities that have become routinely accepted such as speeds greater than Mach 2, all-weather intercept, long-range missiles, and remarkably capable avionics systems. They are designed and built to operate continuously in the environment of ships at sea.

These aircraft of today have grown from past exploratory and development efforts, and in the atmosphere of not always being too certain about the application of a specific technology. Similarly, it is probable that some, but not all, of the work being done today will provide the base of technology for tomorrow's aircraft.

Further, some concepts and technologies may find earlier applications than others. This is the nature of R. & D. and results partly from technical uncertainties and partly because the precise direction of future aviation is difficult to predict. For these reasons our R. & D. programs are structured to provide us with a wide range of options

To cover a broad range of technology options is costly; therefore, where we share common interests with the AF, Army, FAA or NASA, we attempt to enter into joint R. & D. programs. In addition, we look to NASA as the key source of basic aeronautical research and technology, reserving our resources for problems and projected needs unique to the Navy. We try to avoid duplicating work going on elsewhere. We do try to expand upon and exploit where possible the efforts of other Government agencies and the aeronautical industry.

Looking to the future, one likely trend is an expanded air-capability in the Navy. Aircraft can be used to extend and enhance the capability and effectiveness of virtually all Navy ships. However, for ships other than aircraft carriers, this will require vertical takeoff and landing (VTOL) aircraft.

To provide this capability is a substantial technical challenge and we are devoting considerable attention to promising VTOL concepts. We are also studying other VTOL systems not directly related to small air-capable ships but which have possible long-range payoffs. Today we will describe some of these VTOL concepts and indicate why they may be attractive.

We will cover some of the new technology which may have a significant impact on VTOL aircraft, and may offer major benefits in the areas of cost reduction, reliability, maintainability, logistics, and manpower for all aircraft types. In particular, important developments in materials, structures, propulsion and electrical systems will be highlighted.

I have several technical representatives from the Naval Air Systems Command with me today to assist in this presentation. They are led by Mr. William Koven, who is director, advanced aircraft development of the Naval Air Systems Command. I would now like to turn this presentation over to Mr. Koven, who will describe some of the current Navy efforts in more detail.

The CHAIRMAN. Thank you, Admiral, and we look forward to hearing you, Mr. Koven. If you would like to identify your associate, we would like to have their names in the record.

Mr. KOVEN. All right, sir. Mr. Kearns is up at the Vugraph machine. He is our expert on materials. Mr. Lichtman is our expert on engines. Mr. Perkins is our expert on advanced concepts. Capt. Schaufelberger is the project manager on the XFV-12A aircraft, the thrust augmented wing and Mr. Siewert is our expert on aerodynamics.

The CHAIRMAN. Thank you. We welcome all of you.

Mr. KOVEN. Good morning, Mr. Chairman. A large variety of VTOL concepts are being investigated for possible application to Navy and Marine Corps missions. For example, we recently completed a shore and ship based flight evaluation of the CL-84 tilt wing aircraft, and we are following very closely the NASA/Army XV-15 tilt prop development program.

As for our own programs, they are directed to the speed/altitude/size spectrum not presently being investigated elsewhere. In addition we are working on a concept which could have a significant impact on helicopter operations in the not too distant future, the circulation control rotor—CCR.

38-266 O - 74 - 4

CCR CONCEPT

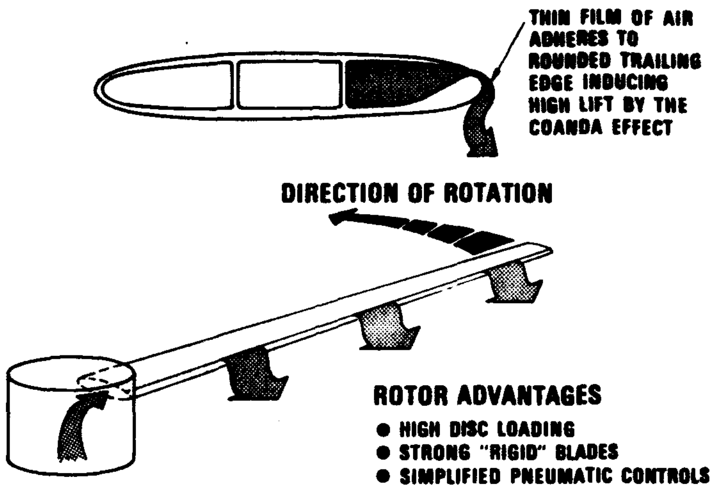


FIG. 1

In the circulation control rotor (fig. 1) compressed air supplied by a compressor is ducted out a spanwise slot over the rounded trailing edge of a hollow rotor blade. By varying the amount of air flowing through the slot, the total lift as well as the lift distribution can be varied as necessary. The prime virtue of this rotor is that it is simple and we would expect it to be reliable. It eliminates the need for many hinges, bearings, and mechanical parts so troublesome to conventional helicopters. Recent wind tunnel tests as well as structural and design feasibility studies continue to show this concept to have great promise. This year we intend to initiate development of a technology demonstrator to prove the CCR in full scale.

Figure 2 illustrates what a circulation control rotor hub of the future might look like as compared to current day articulating rotor hubs.

A lift-fan propulsion system has great potential for providing the Navy with a multipurpose, highly flexible subsonic VTOL aircraft system. One of the lift-fan aircraft concepts being considered (fig. 3) involves three lift fans arranged in triangular fashion to provide both lift and control movements. The apex fan is mounted horizontally in the nose of the aircraft while two aft-fans are mounted vertically with the telescoping retractable hood for VTOL flight. In the arrangement shown, the turbine tip fans (fig. 4) are powered by hot gas ducted from two gas generators in the fuselage. We find the lift fan aircraft significant because it offers good speed (M–0.85), high altitude (40,000 ft.), good endurance, excellent range, mechanical simplicity, a reasonable hover capability, and a comparatively benign footprint. By footprint, we mean temperature and pressure profiles near the aircraft caused by the downwash or exhaust of the propulsion system.

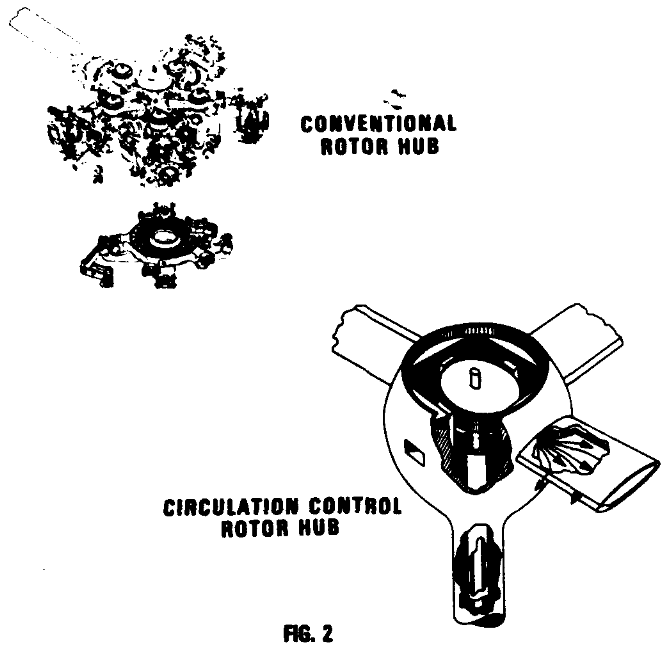


FIG. 2

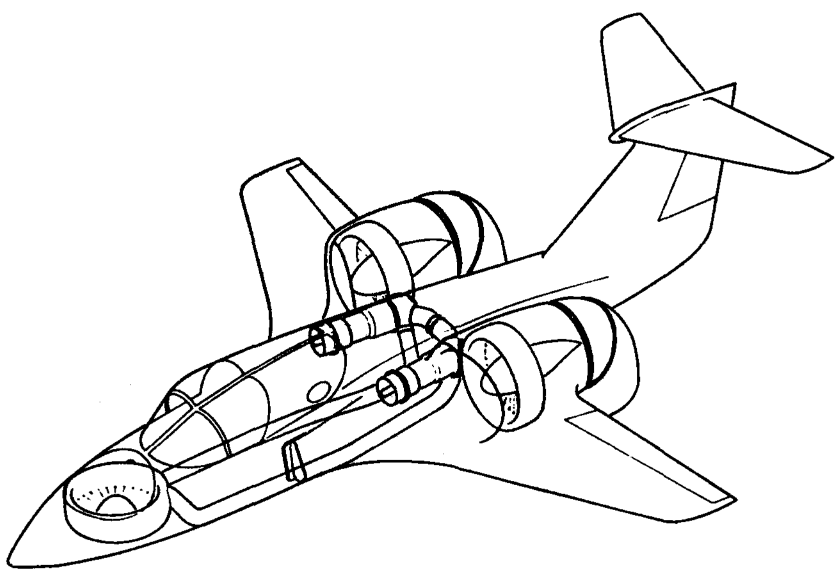


FIG. 3

TURBOTIP FAN

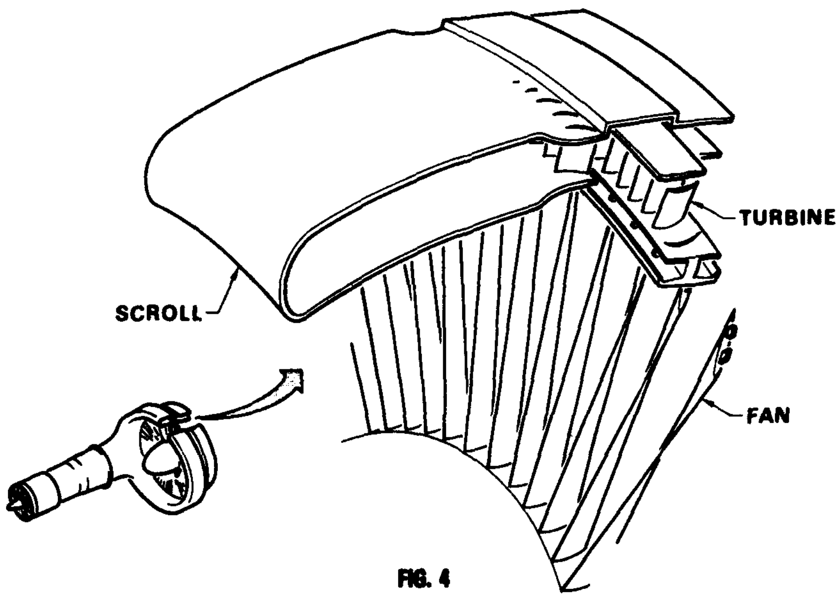
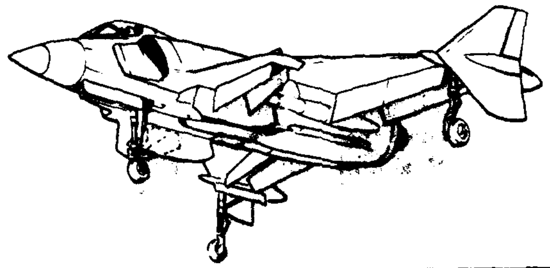
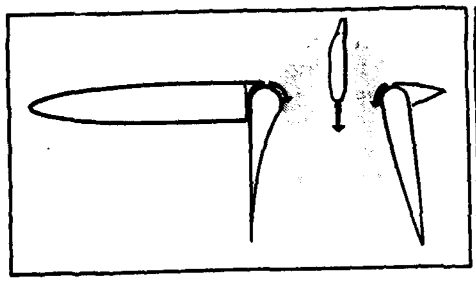


FIG. 4

Finally, we feel that multiapplication capability can be achieved by using the core propulsion system and building larger or smaller fuselages around it (fig. 5). We are currently involved with NASA on a joint exploratory project on this concept.

Lift Concept





INSTALLED ENGINE THRUST	14,070
AUGMENTATION RATIO	1.55
LIFT THRUST	21,800
TOGW (V)	19,500
T/WT	.72 INSTALLED
	1.12 TAKE-OFF

[redacted]

FIG. 6

Control Concept

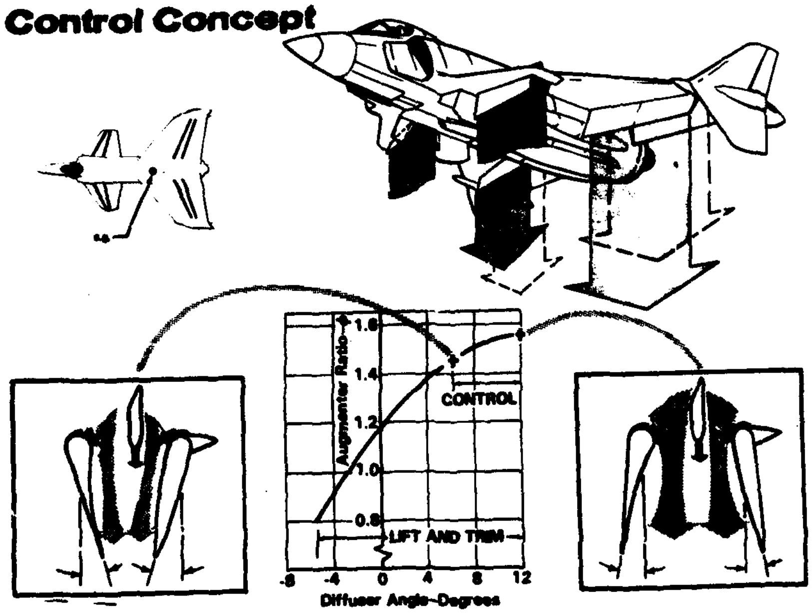
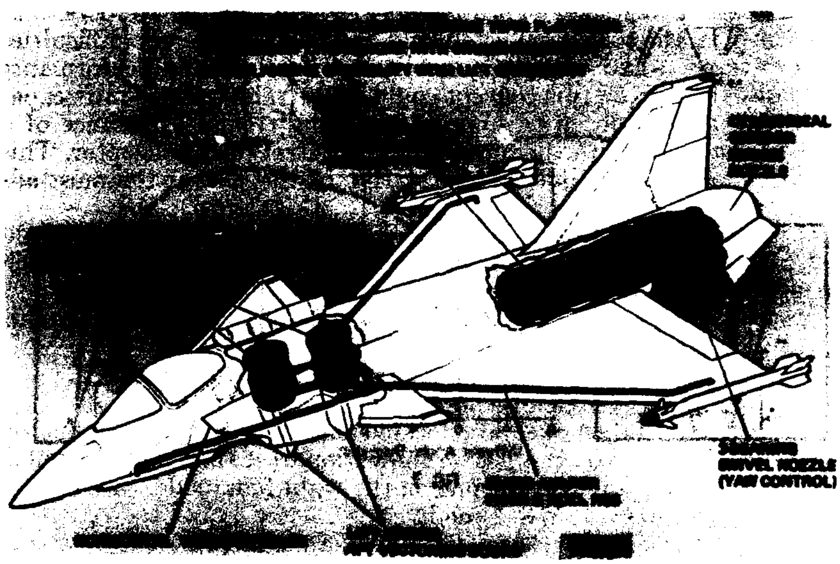


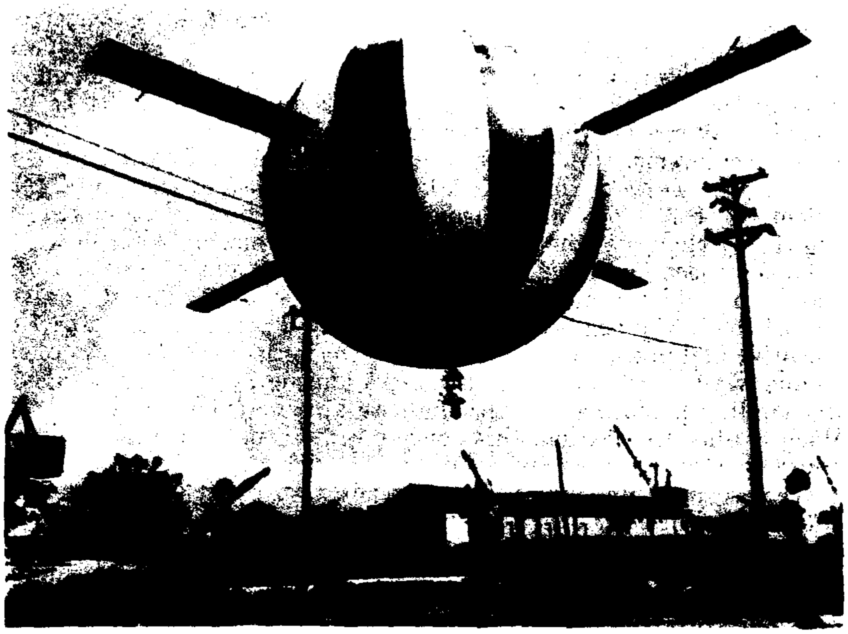
FIG. 7

Our largest and most ambitious project in the VTOL field is the Thrust Augmented Wing (TAW), the XFV-12 airplane. Here, (fig. 6) high velocity, high temperature air is ducted from a basic gas generator to ejectors located in the wings and in the forward canard surface. The high velocity ejected air entrains or pulls in large quantities of the ambient air and thus produces an upward thrust or lift considerably greater than the primary thrust provided by the ejector alone. Achievement of a high augmentation ratio, that is, ratio of total thrust to ejector thrust, is a key to the success of the TAW. Excellent control is provided through the "four poster" arrangement (fig. 7) by changing the angles of the various ejector wing flaps.

This project has been underway for some 2 years now and the plan is to build and flight test two prototype aircraft. The attractiveness of the TAW lies in its potential for high performance, a benign footprint and minimum propulsion system investment. Because of its unique wing arrangement it also offers unusually good short takeoff and landing performance. Although we are currently looking at the Mach 2 plus application, this concept would apply equally well to a high performance subsonic aircraft.

We also have underway a modest effort in a lift plus lift/cruise Mach 2 plus fighter/attack aircraft. It too features a forward-placed canard but differs with respect to its propulsion system. In this case (fig. 8) the propulsion system consists of two lift engines mounted vertically directly behind the cockpit canopy and one horizontal cruise engine which is converted to a lift engine for VTOL flight by means of a swivelling nozzle at the aft end. This concept also offers high performance but the high temperatures and pressures of the direct engine exhaust may create special problems in deck handling and unprepared site operations.





I would like to mention one other VTOL program, the Aerocrane, a hybrid aircraft concept composed of helicopter and balloon elements (fig. 9), which could satisfy a potential need for an ultra heavy lift VTOL aircraft. Although a simplified model has been flown in tetherd flight, we lack indepth technical studies of the Aerocrane at this time. If the many expected and unknown technical difficulties can be overcome and if the very preliminary weight and performance estimates are correct, this concept could conceivably provide lift capabilities up to 200 tons with some of the stability and endurance of a balloon combined with the mobility and control of a helicopter. This capability may be available at a fraction of the cost of the most advanced helicopters.

This concludes the discussion on aeronautical concepts and I would now like to proceed to some important technology developments which are key to the success of future aeronautical vehicles.

Senator GOLDWATER. May I interrupt? Before you get rid of this picture, what RPM are you talking about.

Mr. KOVEN. Oh, between 8 and 9, Senator. Very low RPM.

Senator GOLDWATER. And where would your engine be?

Mr. KOVEN. The engines are located out on the wings or out on the rotors. In fact, you can get an indication of it there on the model. There is a little propeller, the one on the right hand side.

Senator GOLDWATER. Yes. I see it.

Mr. KOVEN. It is a little model airplane engine.

Senator GOLDWATER. That is going to shape them up.

[Laughter.]

Senator GOLDWATER. Thank you.

The CHAIRMAN. You may proceed.

FIG. 10

Mr. KOVEN. The operating environment for aircraft in the Navy is tough; saltwater is everywhere (fig. 10), and we find that the characteristics of the materials available for building engines and airframes determine to a large extent how well this equipment will perform. In addition to the well recognized requirements for lighter weight construction and higher operating temperatures to improve airframe and engine performance, there are demanding requirements for corrosion resistance, ease in maintenance, reliability, long life, ease in fabrication and low cost. We are now using available materials at about the limits of their capabilities. We are working on some new developments that offer extremely attractive improvements for the future. The numbers may not sound dramatic, an increase of 150° F in turbine blade temperature, a 15 percent reduction in airframe weight or a reduction of 50 percent in corrosion maintenance, but advances such as these can double the payload of our aircraft, reduce fuel consumption by 10 percent and save millions of dollars in maintenance costs and manpower. These improvements are particularly advantageous in the versatile aircraft that we need to extend our capability for operation from small ships in an air-capable Navy.

Before mentioning some of the things still in the laboratory in materials and structures, I would like to discuss a development recently completed and now entering service. One of the limitations of the high strength aluminum alloys has been a susceptibility to stress corrosion cracking (fig. 11). Some parts under a sustained tensile stress in our corrosive environment would crack after 1 year or more in service. Repeated inspection, maintenance and part replacement

STRESS CORROSION CRACKING

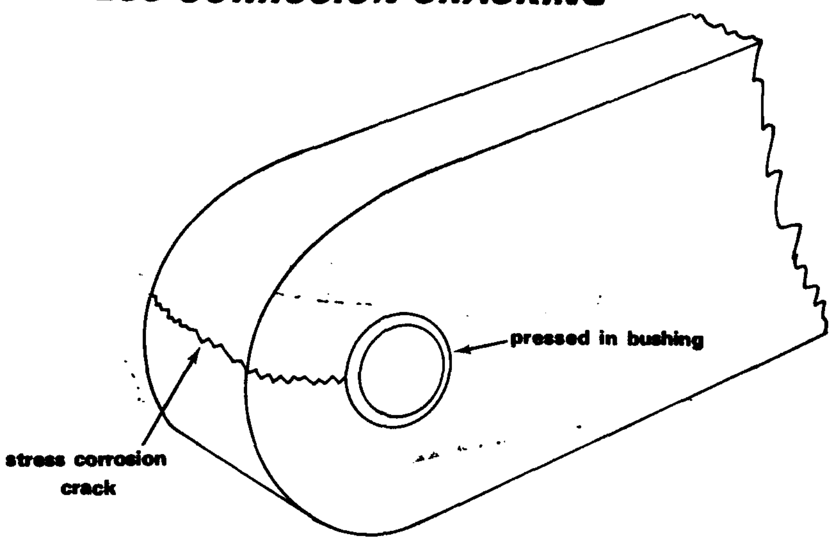
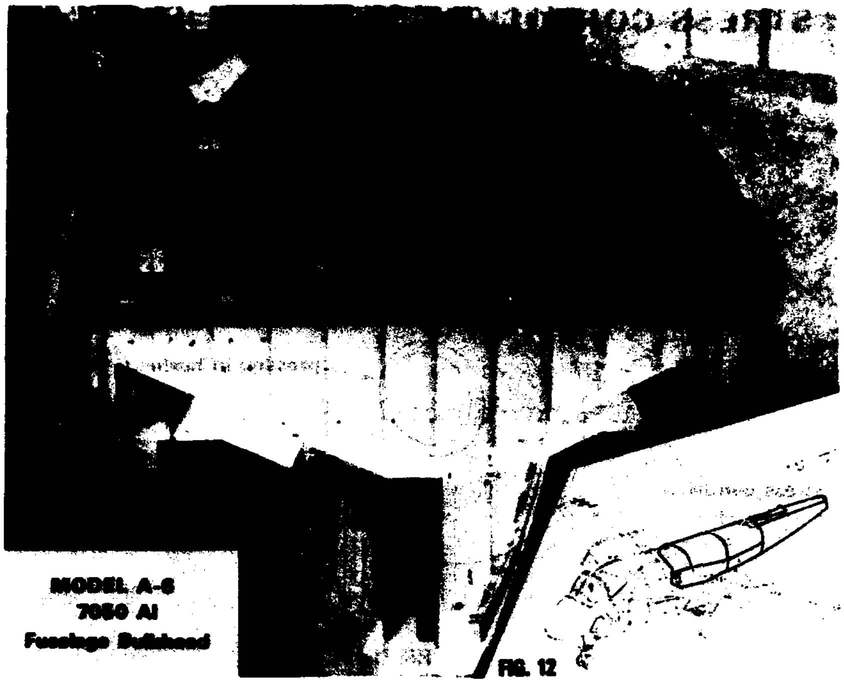


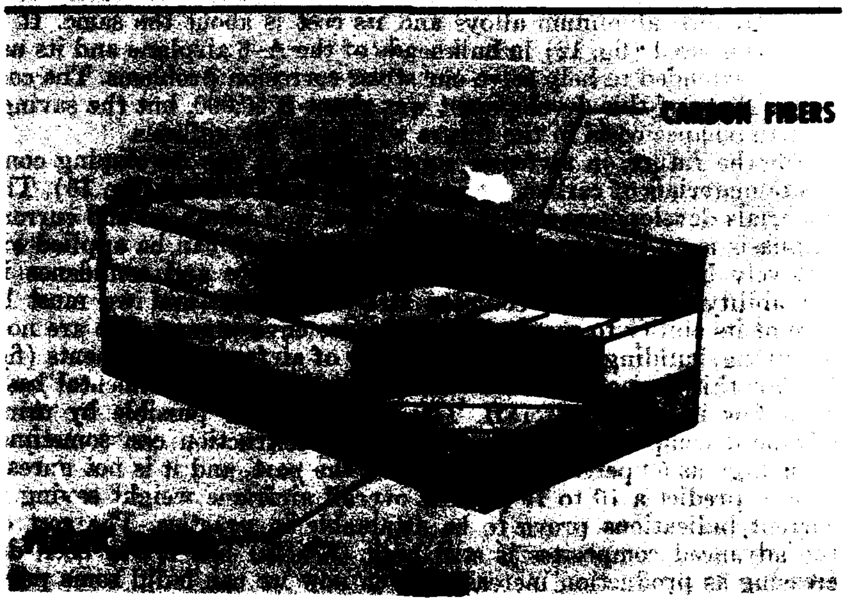
FIG. 11

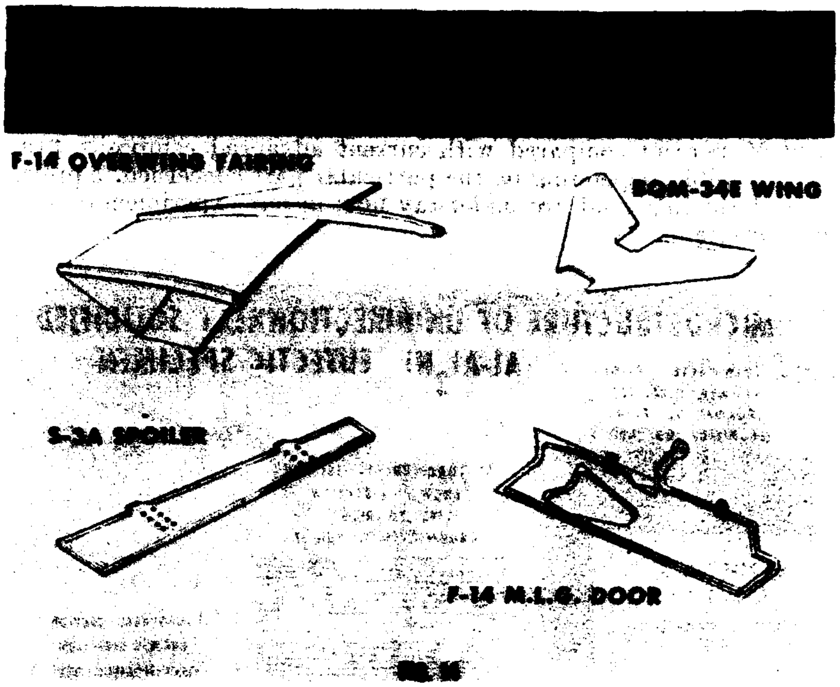
due to stress corrosion cracking has been very expensive. However, working with industry and the Air Force, we have developed a new alloy—7050 aluminum—that is resistant to stress corrosion. It also has better strength and toughness than the current most widely used high-strength aluminum alloys and its cost is about the same. It is now being used (fig. 12) in bulkheads of the A–6 airplane and its use will be extended to help solve our stress corrosion problems. The cost to the Navy of this development was about $250,000, but the savings in maintenance costs in the future will be in the millions.

For the future, in airframe construction, we are developing composite materials of carbon filaments in a plastic matrix (fig. 13). The materials development in this area is now well advanced and current emphasis is on experimental structures. Before it can be applied extensively in airframes, we must gain experience and confidence in our ability to use it in complex airframe design and we must be sure of its ability to survive in the service environment. We are now designing, building and testing a variety of airframe components (fig. 14) for this purpose and will install these on an experimental basis on a few in-service aircraft. The weight saving possible by using advanced composites in place of metal construction can sometimes be as high as 50 percent, depending on the part, and it is not unrealistic to predict a 10 to 15 percent overall airframe weight saving if current indications prove to be attainable in practice. The cost of the advanced composites is still high ($75/lb) but it has been decreasing as production increases. Even now we can build some parts in composites more cheaply than in metal because of the lower manufacturing costs.



FIBER REINFORCED COMPOSITE MATERIALS





REINFORCED THERMOPLASTICS

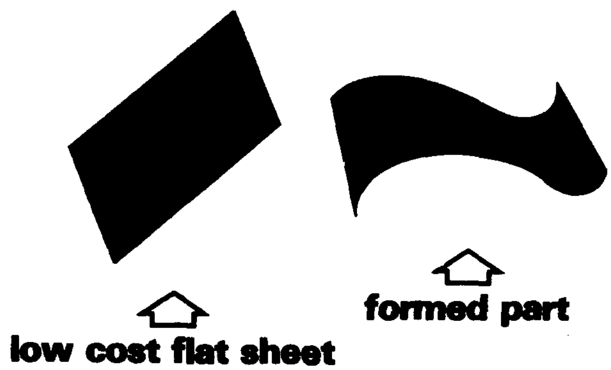
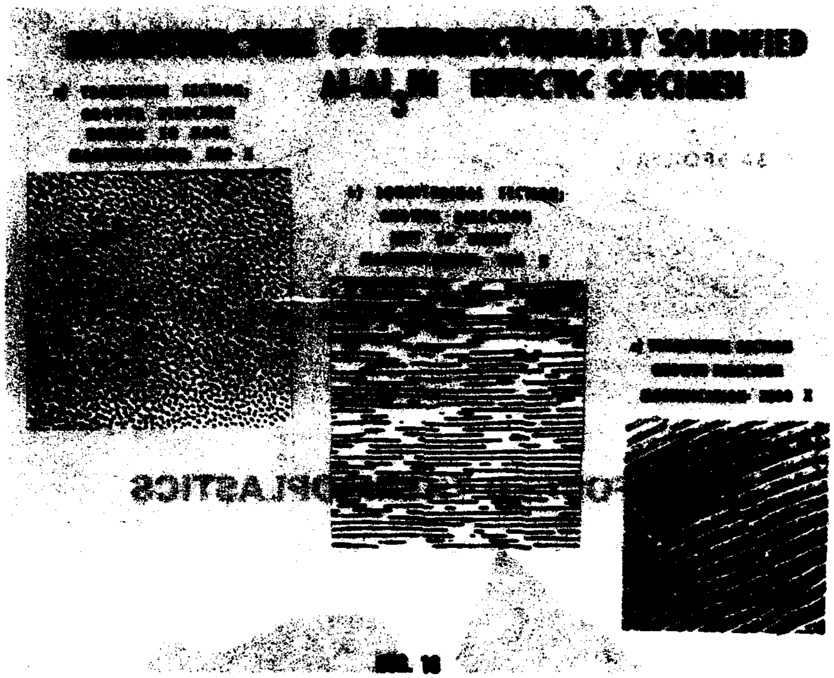


FIG. 15

To reduce the cost of composite parts, we are developing a carbon-fiber thermoplastic composite which can be formed from flat sheet at elevated temperatures (fig. 15). This material should permit use of automated lay-up machinery for low-cost flat sheet and eliminate much of the labor in parts manufacture. An overall cost saving of about 50 percent compared with current advanced composite practice is possible, depending on the particular part concerned. Applications of this material are underway now in our experimental structures program.

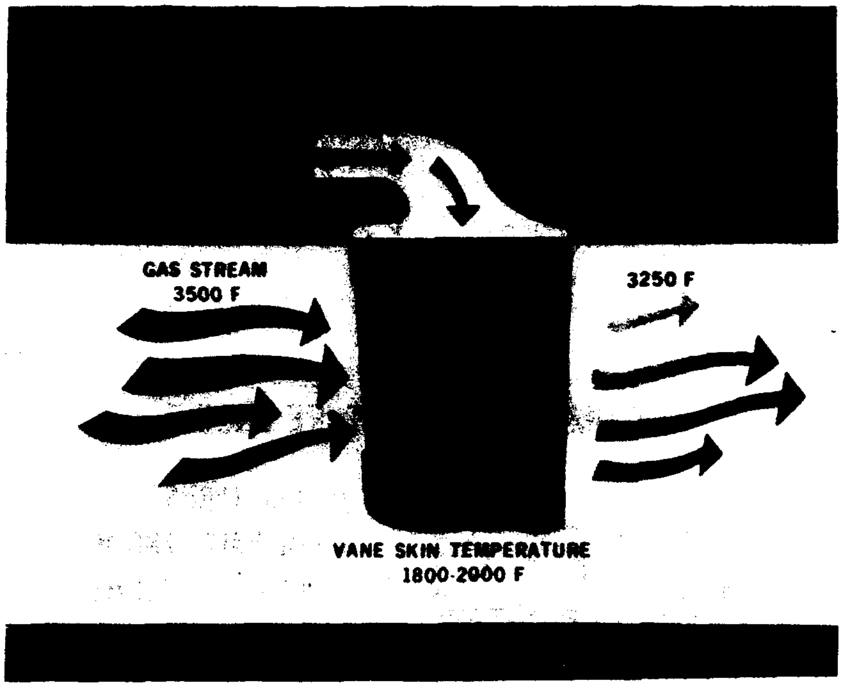


We are also developing a new type of material for gas turbine blading that is very promising and may permit an increase of 150° F or perhaps even more in blade temperature over the 1,800° F allowable with our best super alloys. This is the directionally solidified eutectic. By controlling composition and fabrication practice we can precipitate strong filaments in the metal itself giving very high strength in the direction in which they are oriented (fig. 16). Some of the high temperature strength values measured for materials of this type are more than three times those of our current best super alloys. There is much work to be done before this attractive laboratory development can be converted into useful turbine blading. The other Services and NASA are also engaged in work on directionally solidified eutectics and we have formed a special working group on this topic for mutual planning of an overall research and development program.

I have mentioned just a few items in aircraft materials and structures research to indicate the potential for the future. In other areas,

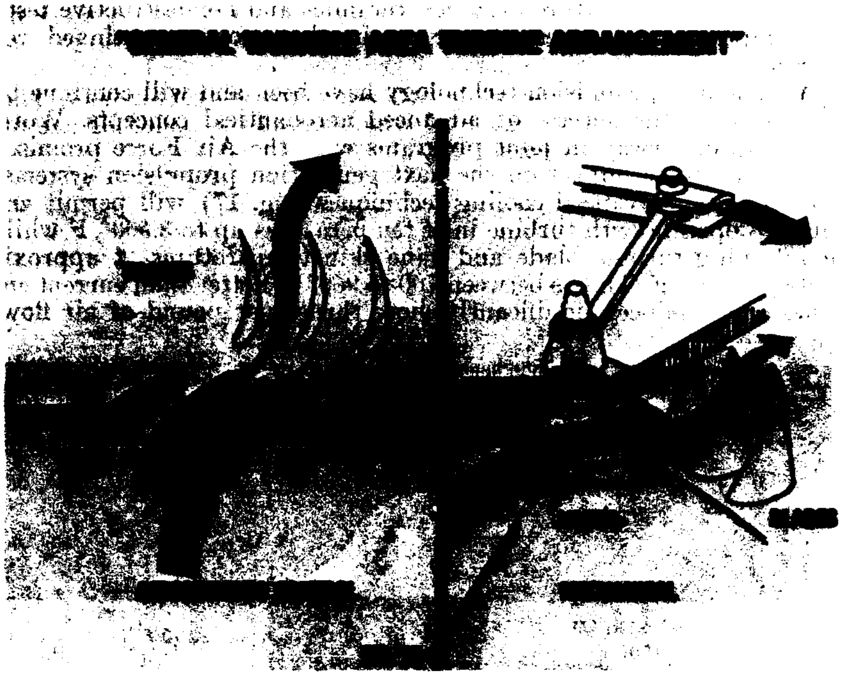
such as high temperature organics, ceramics and nondestructive testing, important advances appear attainable through continued research.

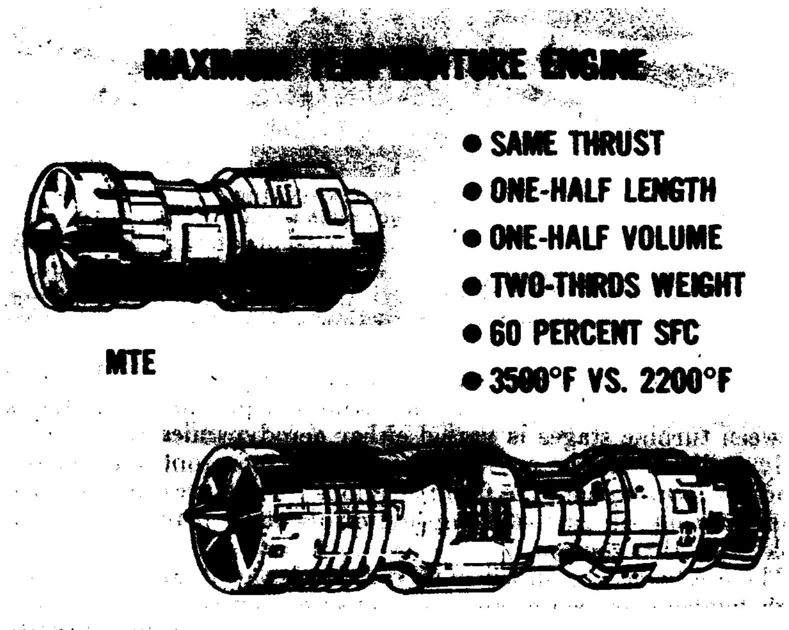
Advances in propulsion technology have been and will continue to be crucial to the success of advanced aeronautical concepts. Work currently underway in joint programs with the Air Force promises to have a major impact on the next generation propulsion systems. For example, advanced cooling techniques (fig. 17) will permit engines to operate with turbine inlet temperatures up to 3,500° F while maintaining turbine blade and vane skin temperatures at approximately 2,000° F. This is between 700 to 900° F hotter than current engines and produces significantly more thrust per pound of air flow.



Another key parameter is fuel consumption. The variable area turbine (fig. 18) currently under development, in which the flow area between turbine stages is varied either aerodynamically or mechanically, will permit the engine to operate at more optimum matching conditions throughout the flight envelope than is presently attainable. Improvements in fuel consumption of about 30 percent appear possible with this concept.

These advances, coupled with the development of high strength/high temperature materials (i.e., eutectic alloys), high heat release burners, and high stage loading compressors and turbines, promise to provide engines of one-half the size and two-thirds the weight, with cruise efficiencies much improved over current jet engines (fig. 19).




● SAME THRUST
● ONE-HALF LENGTH
● ONE-HALF VOLUME
● TWO-THIRDS WEIGHT
● 60 PERCENT SFC
● 3500°F VS. 2200°F
MTE
CURRENT - AFTERBURNING

Finally, I would like to note briefly an important development in aircraft electrical systems. Current aircraft are built with large networks of wires, electromechanical switches, relays and connectors which are, of course, prone to failure and hard to troubleshoot. The problem is illustrated on figure 20 which shows the inside of one of today's modern jet airliners.

Through multiplexed control signal transmission and the use of fiber optics, we hope to eliminate 80 percent of the wiring and in addition, provide immunity from electromagnetic interference. We should be able to replace the electrical components with solid state components and logic and achieve increase in reliability of the order of 250 percent with attendant reductions in weight and volume of about 45 percent.

As was indicated in Vice Admiral Moran's opening statement, there are indeed many new and exciting developments in aeronautical concepts and technology which could have a significant impact in the years ahead. We have discussed just a few of them here this morning.

Again, we appreciate the opportunity to appear before you and are prepared to answer questions and/or provide additional information as you desire. Thank you.

The CHAIRMAN. Thank you, Mr. Koven, for that fine statement. When I see that pile of wiring that was in that last picture, it raises my doubts as to whether I ought to be flying so much. There must

be a broken wire in there some place. I hope there is considerable interest in reducing the great complexity that that represents in that aircraft.

You have described some of the advanced technology of the Navy in exploration, electronics and materials. I understand the Navy Air Propulsion Test Center is also experimenting with synthetic fuels. Could you describe some of your progress in this area?

Mr. KOVEN. Perhaps I should turn that over to Mr. Lichtman.

The CHAIRMAN. All right.

Mr. LICHTMAN. The effort has been underway for several years, Senator. It is in conjunction, with other Services and agencies. I would beg leave to furnish you a more detailed answer for inclusion in the record, sir.

The CHAIRMAN. We will be glad to have that.

[Information referred to follows:]

Mr. LICHTMAN. The Naval Air Propulsion Test Center (NAPTC) is carrying out exploratory development and advanced development work on synthetic fuels for Navy aircraft under the direction of the Naval Air Systems Command. This work is part of a broad Navy investigation on the potential suitability of synthetic fuels for ship, air and shore based applications. The primary objective of this investigation is to develop assurance that Navy machinery will be able to operate satisfactorily on these fuels if their use becomes mandatory in some future energy emergency. If there are unavoidable hardware problems associated with the use of synthetic fuels, the Navy programs will define them so that there is adequate lead time for machinery modifications. All these efforts are fused into a coordinated program by the Navy Energy and Natural Resources Research and Development Office (MAT-03Z). MAT-03Z has also been named as the Department of Defense (DOD) focal point for synthetic fuels Research and Development and as the office responsible for liaison with other government agencies on synthetic fuel matters.

NAPTC has been investigating the potential for the use of synthetic JP-5 jet fuel derived from coal, oil shale and tar sands. Emphasis is placed on JP-5 as it is the aircraft fuel most used by the Navy. The need for additional testing on synthetic JP-4 fuel has been eliminated by the decision of the Air Force to emphasize this fuel in its work on alternate sources of aviation fuels. The recent and current work by NAPTC on the three sources of synthetic fuels is as follows:

Coal.—Information on the state-of-the-art of coal liquefaction developed by the Department of the Interior (DOI) has been evaluated from the standpoint of application to JP-5. It was found that a jet fuel can be made from coal, but little is known about the suitability of such a fuel for actual service use. The DOI plans to include, in future liquefaction research programs, work on the refining of products for Navy use. This work should result in quantities of synthetic fuel for testing of Navy hardware. In the interim, a contract program was started by NAPTC with the Sun Oil Company to produce JP-5 of good and marginal quality from each of two kinds of coal. This will enable us to get an early look at the range of properties that can be expected of coal-derived JP-5 and may result in useful feedback to the DOI programs. The JP-5 obtained will be evaluated in-house by means of standard JP-5 specification tests, material compatibility tests, jet engine combustor tests, and performance and exhaust emissions tests in a small gas turbine engine. Chemical characteristics of the fuel which may contribute to poor performance or health hazards will be studied. The Naval Research Laboratory is cooperating in this phase.

The work to provide experimental fuels and most of the tests described are scheduled for completion in fiscal year 1975. The contract work is being supplemented by in-house studies of the potential for production of JP-5 from coal-derived fluids. A small quantity of a stable JP-5 type fuel has been derived from "Sea Coal", the synthetic boiler fuel used in a sea trial of the destroyer, U.S.S. Johnston.

Oil Shale.—Several experimental samples of material derived from Green River Formation oil shale were obtained from the Oil Shale Corporation for evaluation as JP-5 fuel. These samples had been treated with hydrogen to remove the nitrogen and sulfur impurities found in shale oil and to improve the

chemical and physical characteristics of the fuel. The most severely treated of these samples successfully passed the JP-5 specification tests. As greater quantities of these fuels become available they will be subjected to hardware tests. Earlier work had been done in 1960 in which the chemical and physical characteristics of a JP-4 derived from shale oil were evaluated and found to be satisfactory.

Tar Sands.—A kerosene portion of synthetic crude oil derived from Athabasca Tar Sands has been evaluated at NAPTC. This material was found to pass all JP-5 specification requirements with a good margin. It has been tested in a T63 helicopter engine for 60 hours. Performance of the engine was satisfactory. The post-test condition of the engine is still being evaluated, but no harmful effects have been noted to date. Some exhaust gas pollutants were slightly higher than those measured using a typical conventional JP-5. This effect is being studied and may be due to small differences in the physical properties of the fuels rather than being related to the source. Additional chemical and compatibility tests of this fuel will be carried out, and qualification type tests on other engines will be conducted if they appear necessary. More synthetic fuel of this type can be obtained for such larger scale tests. A portion of the fuel received has been sent to the Naval Ship Research and Development Laboratory (NSRDL) for evaluation of properties pertinent to nonaviation shipboard use such as in diesel engines.

The ultimate objective of the programs now underway is to test the suitability, for operation of aircraft, of synthetic fuels that show promise of being produced in the future. Fuels which pass the small scale screening tests will be subjected to full scale engine tests and flight tests. Such expensive large scale tests will be conducted only on synthetic fuels which show real promise for future production and for which there is a reasonable doubt as to suitability as a JP-5. Negotiations for obtaining these fuels (which would probably be derived from coal or shale) are being conducted by MTA-03Z with DOI and private industry for all DOD departments. Requests for Jet A fuel needed by the National Aeronautics and Space Administration (NASA) for large-scale commercial jet engine combustor tests will also be processed through MAT-03Z. NASA has also indicated a willingness to assist in testing JP-5 in their combustors, if the Navy can make fuel available. A specific Naval Air Systems Command objective which will require fairly large quantities of synthetic fuel is the flight test of a Navy aircraft on synthetic JP-5 by 1976. A specific timetable has been set-up towards this objective which calls for specification tests, materials compatibility tests, combustor and fuel system evaluations and initiation of an engine flight rating test in fiscal year 1975. The above work will be done at NAPTC. Chemical analysis and flammability and fire extinguishing investigations will be conducted by the Naval Research Laboratory; and problems pertinent to compatibility with ships fuel systems will be investigated by the Naval Ship Research and Development Center. With satisfactory completion of these tests, pre-flight aircraft tests will take place at the Naval Air Test Center, Patuxent River, MD. These will be followed by preliminary flight tests and, finally an aircraft carrier landing and take-off demonstration in 1976.

The CHAIRMAN. Sometime ago the Bureau of Mines demonstrated that satisfactory jet fuel could be made from coal. More recently a process was developed that indicated that JP-5 can be made from a synthetic crude oil derived from coal. Has the Navy made any evaluation of the jet fuel derived from coal?

Mr. KOVEN. They have tested a coal-derived fuel in a Navy vessel, I believe. Admiral Moran?

Admiral MORAN. Yes, Mr. Chairman. We have stayed in very close touch with efforts in various departments of the Government on synthetic derivitives to make sure that whatever comes out of their process is understood and we can in fact be a sensible user and customer of that product. The experiment mentioned was an experiment using so-called coal-derived fuel to drive a destroyer for a period of time and it explored the possibilities and problems that might be associated with such a fuel for ship propulsion. We anticipate no serious difficulty in the adaption to gas turbines either in aircraft or other gas turbine applications.

38-266 O - 74 - 5

The CHAIRMAN. Thank you very much.
Senator Goldwater?

Senator GOLDWATER. Getting back to the Coanda effect rotor helicopters, how much would be saved in maintenance costs by using this rotor?

Mr. KOVEN. We do not have any quantitative numbers yet. The people in industry who have looked at it and our own people believe that the improvement in maintenance man-hours would be quite noteworthy. One reason we are going to design and construct a full scale demonstrator is to obtain these numbers.

Senator GOLDWATER. Actually industry has gotten to the point of bidding on one or the Navy has approached Kaman and Lockheed. one of their companies, I believe, to build one of these.

Mr. KOVEN. The Navy is going out on a competitive contract to build the technology demonstrator, sir.

Senator GOLDWATER. Who would do that?

Mr. KOVEN. Kaman and Lockheed are the companies involved.

Senator GOLDWATER. Lockheed is getting another contract?

From your tests out here, what do you think the performance benefits will be?

Mr. KOVEN. It is essentially a stand-off from the standpoint of performance as compared to conventional helicopters. For low speed applications, its major benefits come from the less complex rotor system.

Senator GOLDWATER. Admiral, can you give the committee the reasons why the Navy is interested in the Aerocrane concept?

Admiral MORAN. Senator, I do not know if I can fully answer that question but I would sure like to try.

Senator GOLDWATER. Go ahead.

Admiral MORAN. Naval Aviation, as I mentioned in my opening remarks, is the end result of a long series of experiments and developments, some of which have had applications and some of which have not and some which have been failures and some of which have been successful. You have to look at a thing like the Aerocrane experiment in a fairly broad fashion since it clearly does not fit into the picture as you now have it. It is not a carrier based device and it is not a aircraft that will operate in any of our normal requirements for which we now build helicopters and aircraft.

On the other hand, if we can build a device that will do that kind of lifting job of very heavy weights and place with some precision those weights as we sometimes do with helicopters now, you can see application in amphibious operations and in construction effort, I would see a thing like that going into utility and support work far more than it would in the military scene.

Senator GOLDWATER. That is what I thought. You would not have any place for it on a carrier, say.

Admiral MORAN. I am unable to see the application, no matter how hard I try, sir.

Senator GOLDWATER. Just so you do not get it in close air support. [Laughter.]

Senator GOLDWATER. In conclusion with that question, is the Navy doing any work on lighter-than-air, any other work on lighter-than-air?

Admiral MORAN. We are not doing very serious work in lighter-than-air, Senator. As you mentioned with the NASA witness here, it is a subject that comes up periodically. We are trying to stay in quite close touch with all of the work that is going on with the notion that if some good fallout comes from it, we sure wish to know of it and be a part of it.

Senator GOLDWATER. Do you feel that the experiences you had in World War II using lighter-than-air for antisubmarine work would cause the Navy to be—to still be interested in using lighter-than-air for this purpose?

Admiral MORAN. Senator, I do not believe that we would have a great interest in using lighter-than-air for that purpose and I would cite one fact. The submarines we are looking for today travel at pretty high speeds. If he was making his high speed into a strong wind, your lighter-than-air craft may have a hard time making much ground in chasing him down.

Senator GOLDWATER. That is a good answer.

One further question on the helicopter. I am told by members of the committee staff that they were briefed to the effect that a 4-bladed helicopter using circulation control rotors might achieve a speed of 700 miles an hour. Is that right?

Mr. KOVEN. Perhaps I can answer that. You are referring to the X-wing.

Senator GOLDWATER. The what?

Mr. KOVEN. The X-wing. The X-wing is a 4-bladed helicopter configuration where you stop the rotors in forward flight and then use the rotors as fixed wings to sustain lift; two blades or wings are swept forward and two are swept back. In this condition it would be a high speed aircraft. We have done very preliminary work on this, not very much more than back-of-the-envelope design studies at the moment. It is in the very early stages.

Senator GOLDWATER. You wind up with four wings?

Mr. KOVEN. Yes, sir. In X configuration.

Senator GOLDWATER. What lift affect do you get off that one sticking straight out?

Mr. KOVEN. Well, the two fore wings are conventional swept forward wings and the two aft ones are swept back conventional wings.

Senator GOLDWATER. It would be an X, not a cross?

Mr. KOVEN. Right. It would be an X.

Senator GOLDWATER. I get you. Do you think you can hit 700 miles an hour with that?

Mr. KOVEN. Well, if you keep the fuselage very streamlined and keep the hub drag small it is possible, I guess. I do not really know because it is in a very early stage of study and it is too difficult now to estimate.

Senator GOLDWATER. What is the theoretical amount of power that you need to do that?

Mr. KOVEN. I do not have the numbers on that right now, Senator.

Senator GOLDWATER. All right. Thank you.

The CHAIRMAN. Well, thank you very much. Senator Metzenbaum?

Senator METZENBAUM. Mr. Koven, seeing all that array of electronic components, would you explain why the Navy or the airline manufacturing industry has not already gone to solid state components? It just seems to be such an obvious thing to do.

Mr. KOVEN. I can not explain it and I agree with you. It seems like a very obvious thing to do. It takes time, however, to gain confidence in the capability to exploit a new development on an aircraft and until you have actually demonstrated it in flight and obtained experience with it, you hesitate going ahead with general application.

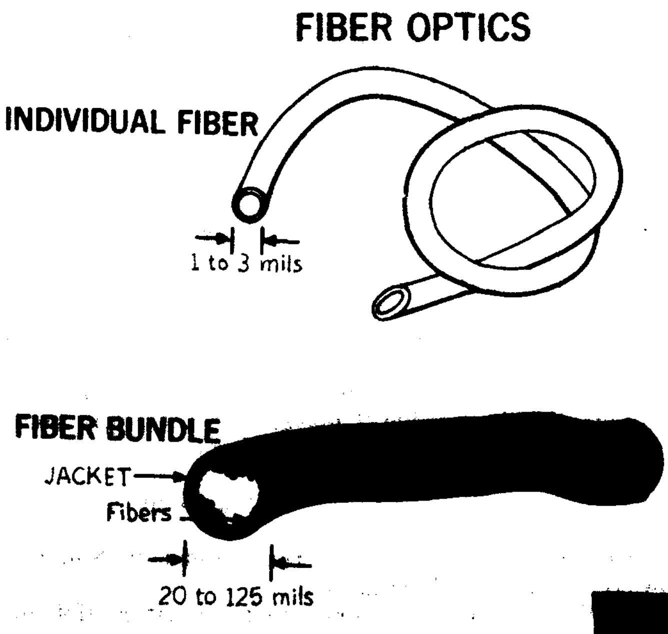
Senator GOLDWATER. Actually would you not even have a better safety factor with solid state components and be able to test if there were a break?

Mr. KOVEN. You would. In addition, maximum advantage of advanced electrical systems can be obtained through the use of multiplexing fiber optics.

Senator GOLDWATER. I do not know the term fiber optics. What does that mean?

Mr. KOVEN. Fiber optics is the use of glass fibers to transmit elecrical impulses. You take an electrical impulse and convert it to an optical impulse, transmit it across glass wires or glass fibers, and at the other end convert the optical output into electrical signals.

It takes two fiber-optic cables of this size—1/16 inch—to do the job that you have to do with conventional copper cables of this size—1½ inch—taken from a typical ship application. (Viewgraph displayed fig. 21.)



[redacted]

FIG. 21

Senator GOLDWATER. There we are on the picture.

Mr. KOVEN. You can see the fiber bundle there. Note the little glass wires, which transmits the light impulses.

Senator METZENBAUM. Actually, the reduction in the utilization of space with solid state components would be quite impressive, would if not, because that whole array might be reduced to just a couple of very small boards.

Mr. KOVEN. That is right. We figure on a typical airplane we could save 45 percent on space through the use of fiber optics and multiplexing.

Senator METZENBAUM. 45 percent of that amount presently utilized for the electronical components?

Mr. KOVEN. Yes sir

Senator METZENBAUM. Thank you very much. Nothing further. Mr. Chairman.

N/WDS BEFORE & AFTER

	WIRE	FIBER OPTICS
NUMBER OF CABLES	302	52
TOTAL LENGTH	4832 FT	832 FT
TOTAL WEIGHT	82 LB	12.6 LB
TOTAL COST	$7.9K	$2.1K

FIG. 22

The CHAIRMAN. Thank you. That is a very good question and it is an interesting thing for me. I notice now on the slide up there (fig. 22) the reduction in the number of cables and the total length and total weight and the total cost, too.

Senator METZENBAUM. May I suggest to the Chairman that he possibly inquire in his capacity of the airplane manufacturers as to why then have not moved in the direction of solid state components, really a more safe means, a more economic means from the standpoint of weight and many other advantages, and it is almost as Mr. Koven indicates questionably why we have not at that point already, why others have not done it. It really is not a Navy project.

The CHAIRMAN. That is a very good suggestion and we will inquire. That is something we ought to know about it. It seems so obvious that one wonders why they have not moved in that direction.

Senator GOLDWATER. I might say as far as the cockpit in the airplane, they have moved very far. But, when you look at the average passenger airplane, when you are sitting there all those buttons that you have to push, they still have to take that wire some place. They have not made that solid state. But up in the cockpit, though they still have a long way to go. They have done a very remarkable job. I forget the amount of wiring in the B-1. Any of you Air Force types know? I know it is well over 80 miles of wire and they are already working, trying to cut that down on the production models.

Admiral MORAN. Mr. Chairman, I would like to add to this question. We are configuring an A-7 aircraft with fiber optics in some major parts of the system. The problem of how rapidly you move into a new application that is a substantial or radical departure from what you have been doing before is a very real problem. It is one where you would like to know with some certainty that you are making the steps ahead which you believe and I believe we would be making if we went ahead a little more vigorously. However, we are tied to a pretty substantial investment, a set of fabrication systems, a set of maintenance people and before we change all of that, we really need a little bit of certainty that we have it in hand. One would hope to get that from this A-7 that we are configuring with the fiber optics in order to go ahead more vigorously.

Senator METZENBAUM. Thank you.

The CHAIRMAN. Well, this miniaturization and elimination of complicating wiring has been a constant push, has it not, with the Navy and with other research areas?

Admiral MORAN. It has, sir, and it is a battle that we have been losing steadily because each time we save a little bit of space somewhere we find three more systems that have to go into the airplane and you get a picture like the one you saw up here.

Senator GOLDWATER. The greatest advance in military aviation will be to stop making black boxes. Every airplane we have built is a beautiful airplane to fly and then you start hanging all that stuff on it.

The CHAIRMAN. Thank you very much, gentlemen. We surely appreciate your presentation. We have found something we need to chew on a little further apparently.

The CHAIRMAN. We are now going to hear from the Air Force and Dr. Walter LaBerge, the Assistant Secretary of the Air Force for Research and Development will be our witness. We look forward to having you, Dr. LaBerge.

[Biography of Dr. Walter B. LaBerge follows:]

BIOGRAPHY OF DR. WALTER B. LABERGE, ASSISTANT SECRETARY OF THE AIR FORCE (RESEARCH AND DEVELOPMENT)

Dr. LaBerge was born in Chicago, Ill., on March 29, 1924. He received a bachelor of science degree in naval science, 1944, a bachelor of science degree in physics, 1947, and his doctorate degree in physics, 1950, from the University of Notre Dame. During World War II he served as executive officer and then Commander of the U.S. Navy Mine Sweeper YMS 165.

After receiving his doctorate degree in 1950, he became a program engineer and then program manager for the Sidewinder missile at the Naval Ordnance Test Station, China Lake, Calif. He participated in the development, production and introduction into the Fleet of the Sidewinder missile, with primary expertise in missle seeker design and kinematics.

From 1957 to 1971, Dr. LaBerge was associated with the Philco-Ford Corporation in various laboratories and operations concerned in research and development, electronics, design, implementation, maintenance, and management, including their programs involved in Gemini, Apollo, and satellites. He first was Director of Engineering, Western Development Laboratories, at Palo Alto, Calif., with engineering and project responsibility for all the laboratories programs. In 1963 he became Director of the Philco Houston Operations at Houston, Tex., and was senior technical and operating executive responsible to NASA Mission Control Center from Gemini IV through Apollo XVII. Dr. LaBerge joined the Research and Development Corporate Staff at Philadelphia, Pa., in 1965, as vice president, and was senior defense electronics staff officer for research and development with direct responsibility for the Philco Corporate research program and approval authority for divisional program proposals and discretionary fund application.

Dr. LaBerge rejoined the Western Development Laboratories in 1966 as vice president and senior operating executive of the division responsible for maintenance and upgrading of NASA Apollo Houston Control Center and the U.S. Air Force remote satellite tracking facilities. From 1967 to 1971 as vice president of the Electronics Group he had senior line supervision of military electronics business with worldwide operations including satellite control facilities, communications satellites, and large antennas for commercial communications satellites.

In 1971 Dr. LaBerge went to the Naval Weapons Center in California as Deputy Technical Director and in June 1973 became Technical Director. In this position, he was responsible for naval weapons development programs conducted at the Center, for research and advanced technology work in support of these programs, and for the technical facilities. He acted as Deputy Program Manager to the Naval Air Systems Command for advanced aircraft weapons systems, and for the Naval Ordnance Systems Command for shipboard point defense weapons systems, antiradiation missile systems, air-to-surface weapons, and shipboard point defense systems. He also was responsible for joint service programs conducted with the Marine Corps, Army, and Air Force.

Among the awards that Dr. LaBerge has received are the California Legislature Resolution of Appreciation for Sidewinder Contribution, 1957; California Junior Chamber of Commerce Award, one of Five Outstanding Young Men of California, 1957; University of Notre Dame, Centennial Award to 50 Outstanding Scientific Graduates, 1967; and Navy Superior Civilian Service Award, 1972. He is a member of the Research Society of America and the American Society of Professional Administrators. He has served on the Defense Science Board Panel on Remotely Piloted Vehicles, 1971–1972; and the Chief Naval Operations Industry Advisory Committee on Telecommunications, 1972.

Dr. LaBerge is married to the former Patricia Anne Sammon of River Forest, Ill. They have five children: Peter Robert, Steven Michael, Jeanne Marie, Philip Charles, and Jacqueline Anne, and reside at 1300 Capulet Court, McLean, Virginia.

STATEMENT OF DR. WALTER B. LaBERGE, ASSISTANT SECRETARY OF THE AIR FORCE, RESEARCH AND DEVELOPMENT

Dr. LaBerge. Good morning, Mr. Chairman. I thought if you wish I could continue the discussion of the wiring problem for a moment.

The Chairman. Very good.

Dr. LaBerge. The B-1 does attempt to work the problem. We believe we will have about a thousand pounds of wire eliminated by a multiplexing system. This is the first time we will have tried it on an aircraft of this size in this degree. It is essentially equivalent to the system the telephone company uses. You dial a code and

through a single wire send this code to various parts of the aircraft. There is a receiver which decodes it and activates a landing gear, flap, or whatever it is that you commanded depending upon that code.

The 747 had, in its early development cycle, committed partially to a system of this kind, but had some difficulties which precluded full utilization of the scheme. I think all of the commercial and military aircraft visionaries are going to learn from the B-1 experience.

Up until now one of the primary rules of aviation safety has been to have a single, physical wire connected to each of the vital parts of the aircraft. The YF-16 lightweight fighter now has a fly-by-wire system which is entirely electronic and will do the things that were talked of previously about signaling for aircraft control. Most of the B-1's physical equipment beyond the cockpit area will be controlled by this digital system.

We now have that system checked out and it does look to be operable and is not now a pacing item in the B-1 schedule. It had been a pacing item because it was a new technology, but it does look as if it is going to go quite well and based on that, I would expect that this class of thing can straightforwardly go ahead.

The CHAIRMAN. Good.

Dr. LABERGE. If I could, I would like to enter for the record my statement and because of the relatively limited time, skip to a few of the pieces of it which I think are particularly important.

The CHAIRMAN. That is acceptable. The full statement will be placed in the record in full (see p. 72).

Dr. LABERGE. Thank you, Mr. Chairman.

I do appreciate the opportunity to be with you. I wanted to highlight first the importance of two facility programs which we have before us, not that they are advanced aviation technology, but they are crucial to the test of all of the new aircraft structures and engines that we expect to be testing in the future.

I want to reinforce both the combined NASA and DOD positions in support of the high Reynolds number test facilities proposed in this year's budget and the aeropropulsion system test facility which will be in a future budget. These are quite expensive. We believe they are very important and in order for ourselves to be sure that the costs are in fact able to be justified, we have talked with both the commercial and the military engine and air frame suppliers and believe we can get them to support, with you, these facilities. They are crucial to any advanced aeronautical system which we will be testing in the future.

The importance of simulation I think is becoming for us, more and more clear. The opportunity is much more available to us now to do this reasonably economically, and with the advent of large scale integrated circuits and with high power computers, we can quite well simulate such things as air-to-air combat and air-to-ground combat. We have a major program for simulation of air-to-air combat where we hope to understand not only the requirements of our air frames and our control systems, but also in the training of our

pilots for successful air-to-air combat, and that is one of the major programs that we are presently undertaking.

The first units are nearing completion. The first unit will be tested starting in September of this year and then will go down to Luke AFB, Arizona for use down there.

We are not only simulating the 6 degrees freedom of movement and a full 360 degree cockpit visibility, but we are attempting through about 31 different air compartments in the seat to simulate forces on the pilot so that he will get the physical feeling of flying.

I think it is becoming more and more clear to us from the experiences in the Arab-Israeli War that training is a very very important part of air combat, and I think we will continue to try to understand the important characteristics of our training and be able to measure how well we do.

Senator METZENBAUM. Would you care to elaborate on that statement?

Dr. LABERGE. The Israeli pilots, flying equipment substantially the same as that of their opposition, were trained to a very fine point and in air-to-air combat had a just overwhelming advantage. As you talked to them about what is important, what to them was important, was that they had the opportunity to train, to understand their equipment, and to physically get a chance to fly in combat-like conditions. I think we have known that for a while.

Senator GOLDWATER. Before you go on, Doctor, I have flown the *simulator at McDonnell-Douglas that has the air pad.* Of course, that was just to tighten up the belt. The one at Northrup actually puts the "G" forces on you by centrifugal force.

Do you think it is preferable to have air-to-air compartment simulation rather than the actual forces? Have you abandoned that Northrup concept?

Dr. LABERGE. We have for this air-to-air simulator, where we wish to have a continued motion unconstrained. Namely, the pilot can take any manuever possible, going to a situation half way between simulating motion as well as G forces. We have a limited motion where you get the feeling for some G forces, but you can not continue because of the transverse position limits. And we supplement this with the air bags.

We are looking at the Northrup approach. It seems to us more important to give full flexibility to the pilot in all of the maneuvers possible.

Senator GOLDWATER. Is the computer cost still the major cost *component of the simulator?*

Dr. LABERGE. It is about matched by the optical and mechanical systems. I think we will find that the computer costs will go down but in the main, the optical and mechanical systems are still expensive and what we are hoping is that we can find out on this first unit what is important and scale down the mechanical/optical part while keeping the computer system essentially as it is so we can fly any and all aircraft in any and all conditions .

You might be interested, Senator, that this struck home to all of us in the sense that we simulated three highly variable combat air-

planes, an F-4, a Mig-21 and an F-15, and educated one pilot very carefully on where his airplane—flew best, and then took pilots who had not gone through this special training and let them compete against each other in the simulator. The F-15 performed very very well against the Mig-21 until it went up against the Mig with a pilot who really knew how the Mig-21 worked. The Mig was able to quietly sucker even the F-15 into a position where he was dominant about 15 percent of the time. Given a short bit of training the pilot of the F-15 won all of the time. I think it is just important that we know where airplanes operate best and that we use the simulation to teach people by physical experience what happens when they do not operate the airplane essentially as they were designed to be operated.

Senator GOLDWATER. Well, this is a very expensive bit of equipment, but I can assure the members of the committee that it saves money. The Army Helicopter School at Fort Rucker, Alabama will save from $100 to $1,000 an hour by simulated training. The airlines are now doing their line checks with simulators. I am sorry to say that when our pilots in Vietnam first went up, except those who had been in Korea, none of them had ever had air-to-air combat training and it was just lucky that they ran in to missions flown by people who had not had as much exposures as we had or we would have had terrible losses.

We are now training our pilots and what you said is true, even in actual training, but the simulator will make it possible for a young pilot to understand the forces of combat flying and will not have to be constantly bothered by people who are safety conscious.

Dr. LABERGER. Yes, sir. I think that is particularly important. If you had to pick one thing that the Israelis said their management allowed them to do which was helpful, it was that they allowed them to train in combat-like conditions. They could pull as much as the airplane could pull with no safety restraints. I think in peace time we can not go that far, but we can do a great deal with the simulator.

With respect to the field of propulsion, I think it is most important that we all realize that the major fighter aircraft advances are really keyed by the remarkable technology we all have in this country in the engine business. We have a number of programs where we are attempting, with the Navy and with the NASA in cooperative efforts, to advance that technology. They include development of structural understanding through computer programs, namely, a way to stop a little bit of "cut and try" and to get a little bit better understanding of our structures through computer usage.

Next is the development of the advanced high strength composite materials. We have an attractive program in this regard and here we are quite closely tied to what the Navy is doing.

We believe as does the Navy, and we have a cooperative program with them, that the variable bypass, variable cycle engine is a necessary future requirement. I did have the opportunity to get up in the SR-71, and I understand there was some earlier discussion of this aircraft. The SR-71 has a bleed system which changes the pressure within the turbine engine with Mach number and altitude. It is a technique that has been known but what needs to be done is to be able to vary the engine cycle over the whole flight region of the

aircraft in a very reliable, efficient way and we are in the process of learning how to do it.

We have, I think, a strong interest in the possibilities of nuclear power. We are planning a modest program to start to evaluate its potential. We initially propose to not spend a great deal, but to start laying out the tests which will allow us to see whether the technology has moved far enough to make nuclear power a reasonable thing for a large aircraft.

A generation ago, or maybe 10 years ago, the technology was not sufficiently advanced. It now appears to be that perhaps 10 years from now it will be, and we need to do those things that allow us to get into position to exploit it.

We are looking, as the Navy described, jointly with them at synthetic fuels and the use of fuels generated from shale and from coal. That does look straightforward. It is something, though, that needs to be carefully done and thought through.

We are heavily embarked on a program of synthetic materials, looking at the graphite composites primarily. We find that we can make very substantial savings in cost as well as very substantial increases in performance using these materials. We already have the tail surface of the F–15 built of composites. We are attempting to take a large wing structure like the B–1 and make it out of composites with the expectation that we can get very substantial reductions in weight and in cost. We believe we can also, with these materials, get something which allows the wing to bend and twist without destroying its characteristics as an air foil. As you know, when an aircraft lifts away, it does this principally through the loads on the wing and this causes a deformation of the wing. When the wing deforms, it does not turn out to be as good an air foil as it was originally, and you get a less efficient operation.

We think with the composites we can tailor this bending so that we can keep the lift characteristics essentially optimal, independent of load.

One other example of the use of composites might be landing gears where about 90 percent of the original billet, which is the start of the landing gear, is machined away to get the central structure which is left. It turns out that we think we can directly avoid this by going to composite materials with a very substantial reduction in weight, an increase in useful lifetime, and surely a decrease in cost.

In the new technology areas we are discovering something which has been known for a long time, that under high G, the heart cannot pump the blood to the brain when you are essentially sitting in the direction of the G forces. If you can lean back and take the G's as one does in the Apollo system, you can survive and operate with greater efficiency at very high G levels. We are exploring, in the YF–16 and to a lesser extent in the YF–17, the tilt-back seat and we have found, for example, that in the YF–16 the pilot gets the sensation of only 4½ G when he is really stressed up to 6 or 7 G's. This will allow us to take better advantage of the new airplanes we can build that can sustain flight at 9 or 10 G. Unless we do something like this we will not efficiently use the pilots under these high G's and so we are looking at the whole system

of tiltback seats, primarily to get higher efficiency from the aircraft that we now can design and build.

We are looking at the digital signaling system. The program within the Air Force is called the DAIS. It is a cooperative program with the naval facility at Johnsville which is working a corresponding part of the program for the Navy together with us.

As I said, we are looking at fly-by-wire. We think that we can get systems which allow the safe control of aircraft through digital programing by computers. I think all of us know that if we can make it safe, we can make the aircraft maneuvering systems much better than they are now.

We are looking at direct force control. This is a system where you don't have to bank to turn but you can get translational forces which can move you sideways or up and down without banking into a turn. It turns out, if you can do this, you can get about the same forces that you got before but you get perhaps as many as five times more opportunities to shoot your guns if you don't have to point the airplane in the line of the directional motion. This is a very interesting new program for us.

We have a program for high supersonic flight. We are looking at new technologies and the thing that I wish to assure you is that we do in fact have a very cooperative program with the NASA and the Navy. This I think is truly one set of programs that Admiral Moran's people take care to tell us when they have something of importance. We work quite closely with them and I think we do in this instance share the benefit of each other's work so equally that you cannot tell by the color of the suit who is doing the work.

We would like to finish by saying we are doing some work on hyper-velocity vehicles. Our X–24 vehicle test program is nearly completed. We are looking at a change in the vehicle configuration in order to allow us to go to higher speeds and to higher cruise conditions. We would expect to be able to launch from the B–52, and get to about Mach 5 at 100,000 feet with a controllable aircraft.

We do wish your continued support this year and I think we do have a program of substance and I would promise you it is one which effectively makes information from our side as available to others as others have made it to us.

Thank you.

The CHAIRMAN. Thank you very much, Dr. LaBerge, for your summary statement. We are glad to have the full statement for the record.

In the first part of that statement you discuss a number of new research and development facilities. How do such test facilities relate to the use of remotely piloted vehicles for research purposes.

Dr. LABERGE. Well, I think it is a three-phased program and the country is now embarking on all three phases to see what the ratio of effort should be. NASA is exploring how you better calculate the effects of aerodynamics and they have a very fine program which we are working with them on which someday may allow us to not have to test everything in the wind tunnel.

We have four facilities which we are coming to you on for wind tunnel testing, two from NASA and two from the Air Force, and we with the NASA are exploring their AMES program. They are

in fact monitoring our YF-16, and our initial confidence in our spin testing is going to be derived from some work that they have done. Our confidence in future aircraft will depend on some of the scale modeling they are doing.

Essentially, we are trying to make sure that the very expensive aircraft are not subject to catastrophic situations, subject either to the loss of life of the pilot or the loss of the aircraft. So I think our RPV efforts will let us try these things before we have the courage to put a man or a machine into test. They do not, however, substitute well for the data taking end of the business.

The CHAIRMAN. I was glad to have you give us assurance that there is great cooperation between all of the R. & D. institutions, both military and civilian, and that is a good thing. But I wonder if you think the total U.S. R. & D. effort on advanced aeronautical concepts is being funded adequately. Are we spending enough in this area?

Dr. LABERGE. That is a very hard question to answer without the context of the whole program. This year's program I think I agree to. We are going to have to put more time and money into the advanced concepts. This year the Air Force I think has a sound program but it is a constrained program in the sense that it must finish several very expensive things that it is undertaking in programs like the B-1 and finish the F-15 and the A-10. I think we are getting much more for our money than we ever got before by the integrated program we have and we are going to have to put more money in.

The CHAIRMAN. Have we, fallen behind other countries, do you think, in the provision of first class aeronautical R. & D. facilities?

Dr. LABERGE. We are falling behind. The Europeans have, both in England and France, facilities which are better than our current facilities. They will not be as good as the ones that we propose to build. The European community this month is again resuming discussions of their program to enhance their facilities and they intend to embark on a program much like the one we talked to you about.

The CHAIRMAN. What would you envision is the possible schedule for the development of a nuclear aircraft and what size aircraft would this be and how much would that cost?

Dr. LABERGE. May I supply that for the record, precisely, because we have tried to go through this, but it is likely, if at all, to be at least 10 years away. There are some very substantial hardware problems. The principle of operation is clear. The hardware is just not clear. In our present guess on weights, it will drive you to aircraft of the size of 747 or larger, probably in the million pound class. And we have estimates on cost.

I would rather, if I may, provide them for the record. It may be quite expensive.

The CHAIRMAN. That may be done but as you see it, that is about 10 years away before we can really be into that.

Dr. LABERGE. Yes, Senator.

[The information follows:]

The development of nuclear aircraft technology could take between 12 and 15 years. The size aircraft for which the technology would be developed is estimated to be in the order of 1.5 million pounds (twice that of the 747). The cost

of technology development could range from $900 million to $1,700 million depending on options in the development program.

The CHAIRMAN. Well, thank you very much, Dr. LaBerge. We appreciate your testimony and the material you are going to furnish us. It was interesting. We are going to have you back again soon for another look as we keep up with what you are doing.

Dr. LABERGE. Thank you, Senator, and it turned out to be approximately 90 miles of wire in the first B-1, much of which in the end could be replaced by a suitable digital system.

The CHAIRMAN. Thank you.

[The prepared statement follows:]

PREPARED STATEMENT OF HON. WALTER B. LABERGE, ASSISTANT SECRETARY OF THE AIR FORCE, RESEARCH AND DEVELOPMENT

Mr. Chairman and members of the committee, I appreciate the opportunity to appear before you today to discuss those facets of technology that are of particular interest to the Air Force and which have the potential to significantly contribute to new aeronautical systems. Rather than review specific aircraft designs, my remarks will center on those technologies with broad future application.

First, we recognize that success in the development of superior aircraft is dependent in a major way on the availability of adequate research and development test facilities. The Air Force has recognized for some time that existing aeronautical facilities are becoming increasingly inadequate to do the job that must be done. Under the auspices of the Aeronautics and Astronautics Coordinating Board, senior representatives from the Department of Defense and NASA have developed a coordinated plan to provide the nation with the technical facilities needed to develop new aircraft and supporting aeronautical systems. This plan includes two Air Force and two NASA wind tunnels. The Air Force tunnels are the High Reynolds Number Test Facility, HIRT, and the Aeropropulsion System Test Facility, ASTF.

The HIRT will provide full-scale Reynolds number flow in the transonic Mach number range where mixed subsonic and supersonic flows require that major dependence be placed on tests rather than on theoretical analysis. Experience has shown that extrapolation from the lower Reynolds numbers available in current wind tunnels to full-scale values is often grossly inaccurate and results in less than desired performance capabilities from the aircraft. Present tunnels do not allow for proper simulation of transonic flows. In fact, tests in our currently available transonic wind tunnels must be conducted at Reynolds numbers which are up to 15 times lower than current aircraft operating values. The HIRT facility offers great promise for reducing aircraft development time and for enhancing overall system performance and efficiency.

The ASTF will overcome the deficiencies in our present propulsion test facilities. The deficiencies I speak of relate primarily to the inability to test complete aircraft propulsion systems under simulated flight conditions.

Equally important to producing superior aircraft is the task of training pilots to fly them. Simulation is expected to play an ever increasing role in pilot training, and the Simulator for Air-to-Air Combat, which will be operational next summer, is a leading example of our efforts along these lines. This two cockpit simulator will have six degrees of freedom and full 360 degree out-of-the-cockpit view. The visual system is totally new and was developed expressly for this simulator. Even the pilots' seats are new technology. These seats contain 31 air compartments which are computer controlled to simulate acceleration forces on the pilot's body while he is maneuvering the simulator. The experience gained in the development of the Air-to-Air Combat Simulator, as well as other advanced simulators, has so convinced us of the importance of the physchological aspects of simulation that the Air Force is co-locating human factors personnel with simulator engineers.

In the field of propulsion, some of the major technology areas to be emphasized over the next several years are improved structural definition, new material application, variable cycle engines, and special purpose engines.

Major structural problems experienced in the development of advanced turbine engines have underscored the critical need for improved structural design criteria and inceased test verification of new configurations early in the development cycle. Structural analysis procedures, instrumentation and test techniques are being augmented by closely integrated Air Force/Navy turbine engine advanced development programs.

Advanced lightweight, high strength, composite materials will be developed for engine static structures, fans, compressors, and turbines. The utilization of these materials has the potential of producing substantial improvements in engines by increasing thrust-to-weight ratios, component speeds, and aerodynamic loadings, while at the same time reducing costs by eliminating component stages and parts.

Air Force mission requirements for efficient operation over a wide range of supersonic and subsonic flight conditions have created the need for a variable cycle in future turbine engines to vary the bypass ratio, pressure ratio, and airflow of the engine to best match the flight conditions. The effectiveness of mid and long term multimission aircraft will be dictated by the flexibility inherent in this type engine. We believe the variable cycle technology represents the next major advance in the development of the jet engine and its use will extend beyond the year 2000. Both the Air Force and NASA are sponsoring programs to increase our variable cycle technology base.

Of continuing interest are special purpose engines that will utilize nuclear power. The Air Force and NASA did extensive work in the past in this area, but much remains to be done with the development components such as long-life pumps, highly reliable vanes, and leak-free and durable heat exchangers. We plan to begin a modestly paced technology program leading toward a nuclear propulsion capability for long range, long endurance aircraft for application in the 1990's and beyond. In the meantime, during the 1980's and into the 1990's, the Air Force will still rely on hydrocarbon type liquid fuels. We are, therefore, studying the possibility and feasibility of deriving acceptable aircraft fuels from coal and oil shale resources. Estimates indicate that it will require at least ten years to fully develop these resources.

In the area of materials, I would highlight the composites which will enable us to either increase payload, range, and maneuverability of aerospace vehicles or to decrease the size and gross weight of a vehicle performing an equivalent mission. The Air Force is currently demonstrating composite empennages and secondary structures in the Lightweight Fighter program, and the F–15 has a composite stabilizer. In addition, other aircraft composite programs have been initiated such as the development of a fighter wing and the "Weapon Systems Advanced Composites Application Program" which will develop bomber-scale wing and empennage structures. In regard to cost, composite structures offer the potential for significant reductions over conventional metal structures. We are attempting to exploit the directional properties of the composite material in wing designs in such a way that the wing will, under combined aerodynamic and weight loads, deform in a prescribed way. This "load conforming" deformation will be obtained while satisfying all other requirements such as strength and flutter. This will allow the wing to control its loading under maneuvering flight at high speeds where adverse load distributions can occur. Thus, future wing designs using composites show promise of achieving "Maneuver Load Control" passively, i.e., without recourse to deflecting auxiliary surfaces.

Also in the area of composites, the Air Force has produced a prototype graphite composite landing gear tailored to a 13,000 pound class aircraft. A 50 percent improvement in fatigue life is indicated with a 30 to 40 percent weight savings. Over the next ten years, we shall continue development of composite landing gears for application to large aircraft.

In discussing advanced aircraft systems, the high-G seat, digital avionics, and direct force control are representative of items of interest to the Air Force. Since today's fighters incorporate an unprecedented level of sustained maneuverability, the emphasis on added fighter agility has raised serious questions as to the ability of the pilot to effectively function in this dynamic environment. Therefore, attention has been focused on development of a high-G cockpit concept whereby the pilot will be positioned to provide added G-protection during extreme combat maneuvers. The program will determine if the high-G cockpit does provide an air combat advantage and whether the implementation of the cockpit is technically viable.

In digital avionics, the Air Force has initiated a program called Digital Avionics Information System, DAIS. In the past, mission information requirements have been established along semi-autonomous subsystem areas such as navigation, weapon delivery, stores management, flight controls, and others for each new system. The trend within each of these subsystems has been toward digital systems each with its unique processing, transfer and display of information. Interaction of requirements between these subsystems has been limited to that necessary to accomplish system integration. The DAIS concept proposes that the processing, multiplex, and display functions be common and serve all the subsystem requirements on an integrated basis. To accomplish this, the information is reduced to a common digital format similar to that in pocket calculators. With everything in terms of numbers of digits, the common computers can switch from handling a television display to a weapon delivery calculation and then to navigation as required.

We are, of course, continuing efforts to develop those subsystems which lend themselves to digital electronics. For example, we expect to begin a Digital Flight Control System project next year to develop and test a digital flight control system. The objective will be to obtain flight validation of operationally representative hardware, software, and procedures. Emphasis will be placed on evaluating digital, survivable, fly-by-wire systems and the evaluation will be tailored to the air-to-air and air-to-ground combat missions. A YF-4C aircraft will be utilized as the design test vehicle and we contemplate possible use of this type system in advanced tactical fighters in the mid-1980's.

Another area of interest is the evaluation of direct force control to enhance aircraft maneuverability. Direct force control is the ability to produce and control lift and sideforce, or a combination of the two, to affect a change in an aircraft's lateral or vertical position without a corresponding change in the aircraft's attitude or angle of attack. The employment of direct force controls have the potential of significantly improving the maneuver and tracking performance of modern tactical fighter aircraft. Studies have shown that a typical fighter aircraft employing direct force controls will have over five times the gun-in-envelope time of a conventional fighter.

To summarize advanced development work in aircraft systems, I should like to mention the Advanced Fighter Technology Integration, AFTI, program just begun this year. The purpose of the AFTI program is to develop a family of flight vehicles which will efficiently and conclusively demonstrate the technical characteristics of promising technologies, both singly and in combination. This program is very closely coordinated with NASA's High Maneuvering Advanced Technology (HIMAT) program which will utilize remotely piloted vehicles to assess high risk technology. The relation of HIMAT to AFTI is that HIMAT will develop high risk technology to the point that the technology can be safely evaluated and demonstrated on the manned AFTI aircraft. This philosophy provides for the orderly identification, assessment, and incorporation of new technologies and will demonstrate the benefits of integrating multiple technologies starting in the initial design process. Flight demonstration of selected integrated technologies can bridge the gap between development and systems applicaiton and will reduce the risk of incorporating advanced technology.

Finally, I wish to conclude with a brief summary of work in the area of hyper-velocity vehicles. Once the on-going X-24B flight test program is complete, we are considering a change in the configuration of the X-24B to accommodate increased fuel and a new engine. Since this new configuration would be capable of very high speed flight under cruise conditions, the airframe would be coated with a heat protection material to protect the basic structure from aerodynamic heating. The vehicle could be launched from a B-52 aircraft to achieve a maximum speed of Mach 5 at an altitude of 100,000 feet. This would permit us to concentrate on high speed cruise conditions and evaluate handling qualities, thermal protection systems, advanced propulsion systems, and the man-machine problems associated with this type of vehicle.

Gentlemen, this concludes my statement. Again, I appreciate the opportunity to appear before this committee, and will be happy to answer any questions.

The CHAIRMAN. We will now hear from Dr. Robert Cannon, who is Assistant Secretary of the Department of Transportation and his function there is Assistant Secretary for Systems, Development, and Technology.

[Biography of Dr. Robert Cannon follows:]

BIOGRAPHY OF ROBERT H. CANNON, JR., ASSISTANT SECRETARY FOR SYSTEMS DEVELOPMENT AND TECHNOLOGY, U.S. DEPARTMENT OF TRANSPORTATION

Dr. Cannon came to the Department of Transportation from Standford University, where he was Vice Chairman of the Department of Aeronautics and Astronautics and Director of the Guidance and Control Laboratory. Prior to joining the Standford faculty, Dr. Cannon was Associate Professor of Mechanical Engineering at Massachusetts Institute of Technology.

From August 1966 to July 1968, Dr. Cannon served as Chief Scientist of the U.S. Air Force. In that position he served as advisor to the Chief of Staff and the Secretary of the Air Force on technical and scientific policy.

Born: Cleveland, Ohio 1923.

Legal Residence: California.

Marital Status: Married to the former Dorothea Collins.

Family: Six sons, one daughter.

Education: University of Rochester, 1944, Bachelor of Science; Massachusetts Institute of Technology, 1950, Doctorate.

Military Service: 1944 to 1946—U.S. Navy, Radar and CIC Officer.

Experience: 1959 to 1970—Stanford University, Professor, Vice Chairman of the Department of Aeronautics and Astronautics, and Director of the Guidance and Control Laboratory; 1966 to 1968—U.S. Air Force, Chief Scientist; 1957 to 1959—Massachusetts Institute of Technology, Associate Professor of Mechanical Engineering; 1951 to 1957—Autonetics Division of North American Aviation, Anaheim, California, Supervisor of research and development of flight control and navigation systems; 1950 to 1951—Bendix Aviation Research Laboratories, Detroit, Michigan, Research Engineer.

Professional memberships: Director of the American Institute of Aeronautics and Astronautics; Tau Beta Pi; Sigma Xi.

Publications: *Dynamics of Physical Systems*, McGraw-Hill, an undergraduate college textbook, and numerous technical papers and articles.

Advisory positions: Chairman of the National Aeronautics and Space Administration's Subcommittee on Guidance, Control and Navigation, and of the Advisory Group of the NASA Electronics Research Center; Vice Chairman of the Air Force Scientific Advisory Board.

STATEMENT OF DR. ROBERT CANNON, ASSISTANT SECRETARY FOR SYSTEMS, DEVELOPMENT, AND TECHNOLOGY, DEPARTMENT OF TRANSPORTATION

Dr. CANNON. Good morning, Mr. Chairman.

The CHAIRMAN. Glad to have you, Dr. Cannon. You may proceed.

Dr. CANNON. Thank you, Mr. Chairman. I am pleased that you wrote and asked me to testify today because the question you asked in your letter, about what opportunities we may see for quantum jumps in airplane technology and systems, is one to which I have given a great deal of thought during the 4½ years I have been in Washington as we have tried to see how to help our transportation system serve our people even better.

I have a special personal reason for being glad you asked me to speak today because I will be leaving the Government next month to take a new job that also excites me very much and this gives me a chance before I leave to share my thoughts of 4½ years with this committee that is providing such important leadership to aviation.

I have eight specific items to suggest to you, but first, I would like to say just a few things about my basis for judging.

First, transportation is a business with a very big leverage. It is 20 percent of the Gross National Product. It is the life's blood by

which we live and interact with one another. It serves us all well. It serves our economic well-being provides us opportunities to work at those jobs we wish, and it serves our quality of life in many ways.

The Department of Transportation's role is to maximize transportation's contribution to that well-being.

Our great transportation system and particularly our wonderful air transportation system did not come about because smart planners in Washington planned it all out and established an official need and decreed the proper technology to be developed. It came about because inventive genius and vigorous free enterprise took advantage of new technological opportunities as they appeared on the scene. Technical opportunities generate progress and nothing else does. It is government's job to foster the development of these technological opportunities.

I would like to speak very briefly about our relations with NASA which are so important to us for with respect to air transportation, NASA plays the key role, the role of the technological stimulator, developing new technological opportunities and confronting the transportation industry and us in the DOT with them. I think confronting is exactly the right word: The interplay between technological opportunities and transportation planning—the continual stimulation and prodding of each by the other—needs to be nurtured and institutionalized.

In these years we have worked hard to structure and restructure this process of prodding each other. Some products of our determination are the CARD study which this committee chartered, the joint Office of Noise Abatement, the R. & D. Policy Office in my shop which is heavily participated in by NASA, and the establishment of the position of Special Assistant for Aeronautics which is occupied by Mr. Larry Greene who is well known to you for his very important contributions on the F–86, the F–100, where he was chief aerodynamacist, and the X–15 and XB–70 on which he was Assistant Chief Engineer. We are still at work on this structuring, because NASA is one of the great resources on which we have to draw.

It is in this framework, then, of new technological opportunities I see on the one hand, and the transportation needs I see them serving on the other, that I offer my observations on your question about opportunities for a quantum jump in aeronautical technology and systems. Specifically I will speak to eight such opportunities I see ahead.

The proper role of the Federal Government is not one of building the Nation's transportation system but of providing an environment in which the privately operated systems can grow and serve the Nation. Thus, the eight specific technological opportunities I will discuss are each focused on removing a constraint to the acceptable growth of aviation by making it quieter, moving it more smoothly, improving its interface with the communities it serves, insuring that it is absolutely harmless to the environment, and reducing its consumption of scarce resources.

The first, of the eight opportunities is in aircraft noise abatement, particularly the application of advanced engine technology and ad-

vanced capabilities in control and handling of aircraft to this problem. The CARD study had as one of its most important outputs the clear finding that aircraft noise is a major limiter on the amount we can allow our air transportation system to grow and on the ways it can serve us.

Historically, in the last decade the excellent work of developing the fan jet concept (in which the Lewis Laboratory placed an important part) has been the single most important contributor to reducing aircraft noise. The large 747's, DC-10's and L-1011's operate at very much lower noise levels for their size than other aircraft ever have before. The refan program of NASA, addressed as a possible solution to retrofitting earlier noisier aircraft, also makes a very important contribution in the continuing effort to reduce noise.

Further, operational concepts (on which im portant early technical work and demonstration work was carried out by NASA) to make two-segment approaches safe and operationally acceptable will, I believe also have a very important effect on reducing noise in the near term.

Looking, into the future at the new contributions to noise abatement that can be made by advanced technology, I see, first, additional advances from the even-higher-by-pass-ratio fan engines. I see us rapidly reaching the point where the core of the jets coming from the engines becomes the basic limiting noise level as we get more and more reduction of machinery noise. I see very important work in understanding the fundamental way in which jets of air at high velocity generate noise as being one of the important technical contributions that must be made and drawn upon.

Below that floor is yet another one which is often called aerodynamic noise, the noise made simply by the body of the aircraft moving through the air, particularly in the landing configuration where the aircraft is very dirty. Basic advances must be made there.

Finally, the two-segment approach is only the first of sequence of things that we can do, and will do, to employ great flexibility in the flight paths of our aircraft as they maneuver near airports to absolutely minimize the noise impact they make on the surrounding area. The greatest technical advance that will permit this is the microwave landing system which will indeed allow us great flexibility in the use of flight paths (where today we can use only a single one or possibly the two-segment one).

Next, if there are to be SST's flying into our airports on more than an experimental basis, basic engine developments must be made which will permit takeoff with the use of afterburners. This will, of course, involve as I see it the use of a variable cycle engine design. It will take a long time and will be an expensive development project, but I feel it is essential to these aircraft being acceptable.

Of course, at the other extreme, there is the fine work that NASA is doing in quiet STOL aircraft. I think that work will have its impact and I will speak to that a little bit later.

The second of the eight opportunities I see is that of application of digital computer technology and new sensor technology to air traffic control to make it even safer, less expensive, both to the user

and to the Government, and more flexible in terms of much more efficient use of the airspace and as I just mentioned, of minimizing noise.

Historically, again we have come a long way from the early days of air traffic control by manual observation of radar screens—which began in the Berlin Airlift in real earnest. Our latest system now in being at over 60 of our airports—the ARTS-III system, and the companion NAS Stage A enroute system—represent the beginning of the use of controllers as managers rather than as routine data processors. We are currently handling substantially more traffic than we handled in 1969, when the skys were filled with aircraft orbiting for 2 and 3 hours before being able to enter an airport, where delays were very large indeed and where air traffic controllers were suffering from great anxieties because of the difficulty of keeping track of the aircraft. Those days are behind us and I hope and am confident that they are behind us permanently. As I say, today we are handling substantially more traffic than we had during those very trying days of 1969.

Turning then to the future of air traffic control, I see a system in which computers carry out the routine control functions and pinpoint surveillance, probably using satellites, allows human controls to maintain complete strategic management of the positions of all commercial aircraft. I see a day when all scheduled flights will be managed from block to block so thoroughly that there will be no waiting time at any part of any trip. Safety will be substantially enhanced in the process, and costs will be substantially reduced. This is a logical extension of the research going on now. We have already laid the groundwork for the system of the 1990's which I firmly believe will have these important characteristics.

My third item is that the digital computer has another contribution to make and this is in cargo origin to destination management. Air transportation has very large economic contributions yet to make as a major mover of freight. Its contribution is the short trip time that it offers, but it is origin-to-destination trip time that counts. This means air plus ground movement. Total trip management through advanced surveillance technology, through computer management of the movement of each shipment, will provide this much better origin-destination service and will be an important contribution in the future.

Our beginning of this is a system called CARDIS, in which shipments from overseas to this country are already being watched through digital computer surveillance. It is interesting that we were able to start the system more readily in the overseas arena than at home because the institutional constraints turned out to be easier there.

My next subject is very quick and it is a purely aerodynamic phenomenon, that of the wake vortex. The wake vortex currently limits our operations near airports. It is the limiting factor on how rapidly we may safely land aircraft. The FAA is moving rapidly to establish a capability to sense and thus to avoid wake vortices through the air traffic management. At the same time, however, it is important that we learn how to disperse these vortices.

The formation of a vortex is areodynamically fundamental to the generation of lift of an aircraft; and the larger the aircraft the stronger the vortex will be. So it is a question, not of producing lift with no vortex motion, but of finding ways to disperse the vortices much more rapidly than currently occurs. At our request NASA is working more and more urgently on this task. A great deal of progress has been made just in the past year.

My fifth item is not primarily one of high technology. It has to do with ground access to airports. But I mention it because it will be a truly essential part of any improvement in the air transportation system.

There are three components involved: a dedicated connection between the airport and the communities it serves, circulation in and around the airport, and very high speed connections between two airports.

Let me speak particularly to the third item. I am thinking of the difficulties we have in being able to use two good airports that are close together, for example, O'Hare and Midway, where we could greatly increase the capacity of a given area but where the problem is one of the airlines being unwilling to serve two places and duplicate all of their facilities and inconvenience their passengers. A particular inconvenience is that of parking at one airport and then returning to the other. If—and I believe it is possible—we can connect such pairs of airports with a 10-minute trip time between them, so that going from one airport to another takes no longer than going from one part of a single terminal to another, then I believe that we can truly move into a period in air transportation development where pairs of airports—and more than two airports—in many cities will serve as an important means of solving the airport capacity problem in very heavy terminal areas.

I think a technological breakthrough that will contribute to this is the tracked levitated vehicle which can move easily at speeds of 150 to 200 miles an hour with very minimal maintenance on the guideways. The guideways must, of course, be elevated or tunneled, but they can be substantially less expensive and require much less maintenance than even conventional rail. I think this is a technology that really will have an important helping effect on air transportation. I will be glad to discuss it a little further if you wish, Mr. Chairman.

Short-haul air transportation in particular is so marginal that only if major ground access improvements can be made will it be viable. I want to say here that we will always try to foster alternatives. We will always try to foster both the air and ground components of travel between cities where the distances are in that region of overlap that can indeed be served by high speed ground transportation, for example. We want to give the people a choice and we want the market to determine what the answer is, but we do not want to constrain. Indeed, we want to foster all of the opportunities that are economically viable to pursue.

Let me turn next to the regime where air transportation stands alone, the long trip transportation regime, and to an item that is high technology indeed. A major advance in combustion technology,

together with a deliberate unstinting program of atmospheric monitoring, will I believe be essential to commercial operation at higher altitudes than we are presently using. We are in the final year of the Climatic Impact Assessment Program (CIAP). The NASA, along with NOAA and many others, have played a very important role with us in gathereing the data and making the assessments needed to carry out this program. The results are not yet available. What we have been able to do is to make the measurements that represent the pieces of the jigsaw puzzle about how the flight of aircraft at very high altitudes could impact the climate and the biosphere of the earth in various ways. We were able to complete our measurements the first time around on the various pieces of the puzzle, and we are now very hard at work putting the pieces together to see what conclusions can be drawn. This will take the better part of the summer and early fall and we will make our report to the Congress as promised in December of 1974.

I can, however, make some comments about the sort of result that could come from these studies. It may turn out to go like the following.

If we do the right things, on time, it may be safe for us to operate at higher altitudes. If we do continue the movement toward higher altitudes, both by increasing the number of SST operations and indeed operations by the subsonic fleet also, specifically with today's engines and fuels, it could lead to serious consequences indeed. And again I will be pleased to discussed these, Mr. Chairman, if you want to take more time.

The right things, the things that we must do, will include first developing the combustors in engines to the point where they can burn with a much lower production of nitrous oxides: second, the monitoring and the carrying out of continuing research in the atmosphere, to learn with more and more confidence what the interactions are and what the dangers may be in absolute quantitative terms.

The engine research, the monitoring and the upper atmospheric research all are in the bailiwick of NASA with some help from NOAA on the latter. They have been working with us up to this point. Even though the DOT budget in this area is on the order of $7 million per year, the expenditures by NASA and NOAA in these areas which are of direct application to this problem are on the order of $30 million and $15 million per year respectively. This work must go on and it must continue to be focused on these specific problems so that our confidence and our understanding and the sureness that we are proceeding properly can be increased from year to year.

Finally, stringent regulation developed with the most deliberate care among the nations must be instituted and maintained. This, of course, is the responsibility of the FAA and they are beginning this work.

We have time to do this one right, without crisis and without damage. Here is one technological advance where we are doing our technological assessment in plenty of time. We know what to do. But we have to start now.

If I can add a personal note to this, I have given this matter a great deal of thought myself and I have a very strong conviction

that we must take no chances at all of disturbing in any way the delicate balance of the environment we live in on this precious planet. Having said that, I also have the conviction that if we can safely operate at higher altitudes and at higher speeds, the contributions which this new level of air transportation can make to the economic well-being of the world will indeed be so great that our generation will make a major contribution by pursuing it.

I think there is an analogy that will explain why I feel this way. Before there were jet aircraft—the people at the centers of culture in New York, Philadelphia, and Boston and the center of government in Washington—had a certain amount of dialog together. But the people on the west coast were really not nearly as active in participation in the culture and business of the country as they have been since the jet came into being. There seems to be a major difference between being able to travel between two points in 4½ hours and taking 8 hours for the trip. California is very much closer to the east coast now, and thus people who live anywhere in our country participate much more heavily in the culture of our country than was possible before the jet.

I now extend this analogy to the cultures and peoples of other countries who, by very high speed air transportation, would also be on the order of 3 or 4 or 5 hours away; and what I see is a true awakening and a true bringing together of the peoples of the world through this medium. I think it is something that we will not want to deny ourselves, and as long as we can be very safe and very sure that we are safe with respect to our environment, I think it is a course of action that is likely to be pursued.

Finally, I would like to talk very briefly about the very long term, three to six decades away. Here the challenge will be for aviation to continue to serve in an era of increasing scarcity of energy and of critical materials.

My seventh item, which is the development of aircraft of continually advancing performance, but without using exotic scare materials for their structures, will call for engineering ingenuity at the highest level.

And my eighth point is that powering such aircraft without drawing heavily on natural petroleum will require a breakthrough in fuel technology or perhaps in other means of propulsion such as you discussed a little earlier this morning.

I suspect that there may be even two more quantum jumps in the speed at which we travel very long distances around our globe, with major economic benefits to mankind each time; but we must be absolutely certain that there will be no adverse side effects. There is a lot of new engineering between here and there.

That concludes my statement, Mr. Chairman.

The CHAIRMAN. Thank you very much, Dr. Cannon. I am pleased with your statement. You obviously have given a lot of consideration to it and set down the various points that you see where we must make this breakthrough and must move ahead all the way from ground systems to new fuels and materials, and I appreciate your assessment of the problems and your indications that DOT is working

in concert with the other agencies concerned with aeronautics and trying to find solutions.

The report that will be issued this fall should be very interesting and I will be looking for that when it comes out.

I did not know that you were about to leave and I do not know how soon you are going to leave Government service. Do you mind telling me where you are going?

Dr. CANNON. Mr. Chairman, I will be Chairman of the Division of Engineering and Applied Science at Cal Tech.

The CHAIRMAN. Cal Tech. Very good. Well, we certainly wish you well.

Dr. CANNON. Thank you, sir.

The CHAIRMAN. And we know that that will be a very satisfying assignment and you have done a great job while you have been here. We have been glad to have had your service on the Federal scene during this period of time and it is most encouraging to find that Transportation, the Department itself, is involved in this effort of finding and developing new technology as vigorously as is being done. We sometimes have a tendency in our Government to get sort of diversified and get several departments working in isolation on overlapping problems but in this case it is quite reassuring that there is close communication and structuring so that you work in concert and not in watertight cells and that, therefore, we get technical assistance flowing from one to the other.

On the long-term fuel problem, do you see that as really getting into another type of fuel rather than the one we depend on now, fossil fuels, or is it improving the technology of using fossil fuels?

Dr. CANNON. Well, of course, it is some of each. In the near term it has to be improving the technology of using fossil fuels since the near term does not hold, as I have come to understand it, the opportunities to use an alternative. But in the long term that I mentioned, the three to six decades hence, aviation, if its growth continues in the ways that our intuition tells us it will, bids to become almost the major user of petroleum, and we all know the rate at which we are consuming our petroleum and how long we can continue to consume it at these rates. That is why I see no alternative but to find a way to fly ultimately without consuming naural petroleum fuels.

As you know, transportation uses about 50 percent of the petroleum that is used in this country. As of today, some 80 percent plus of this is used by highway vehicles, and air transportation uses only a small percentage. But the growth of aviation that my intuition tells me will occur will lead to a very much higher percentage use by aviation three decades from now.

The CHAIRMAN. Dr. Fletcher said this morning that we should not be immediately involved in the development of the SST but we should be working on the technology so that when we were ready to go, then we could provide one with the various necessary safeguards, and so on, that were outlined for it. Do you concur with that general view of Dr. Fletcher?

Dr. CANNON. Yes, I do. I believe that the question of whether this Nation becomes involved in SST development will certainly be one

that will be decided on the basis of the people's wishes just as it was the last time around, and acceding very meticulously to those wishes, we have been careful not to become involved in the fostering or active development in any way of SST aircraft during these years but only of being sure that we understand all we possibly can about what the consequences might be of their flying and particularly being very sure that we either see ways or else develop prohibitions to keep us completely safe from their side effects with respect to noise and particularly with respect to this atmospheric problem.

In the latter case it was quite interesting to find that although we began the study (CIAP) looking for what the impact of SST's might be—bearing in mind that whether this country builds them or not other countries are so engaged and are likely to develop them, and needing to know what our position would be with respect to these other countries and to have the best possible knowledge base for development of a position, we found, however, that not only SST's but subsonic aircraft as they move to higher and higher altitudes are a potential source of danger. And so we have broadened the scope of our activity in this area.

The CHAIRMAN. Do you also feel that other countries are really moving ahead of us in R. & D. facilities in the aviation field?

Dr. CANNON. I think I should defer to Dr. Fletcher and Dr. LaBerge and the other witnesses you have had who have studied these facilities with obviously much more care than I have. The facilities under my own direction or purview have to do largely with our management of the air traffic control system, as you know, together with our upper atmospheric research activities, so that when it comes to wind tunnels, engine facilities, and so on, I look to NASA for information and a judgment.

The CHAIRMAN. Well, thank you very much, Dr. Cannon. We surely appreciate your statement and you have helped us by giving us a little better view of where we are moving and what we are doing and what we have to do. We will look forward to a continuing association with you for the remainder of your Federal term and also when you get to Cal Tech.

Dr. CANNON. Thank you very much, Mr. Chairman.

The CHAIRMAN. Thank you.

In addition to witnesses invited to appear before this committee, we have invited a number of organizations to send the committee a statement for the record if they wish to do so. Without objection, those statements will be printed at an appropriate point in these hearings. (See p. 180.)

That completes our list of witnesses for this morning. We will return on Thursday morning at 9:30 to continue the hearings.

[Whereupon, at 12:25 p.m., the committee was adjourned, to reconvene Thursday, July 18, 1974, at 9:30 a.m.]

ADVANCED AERONAUTICAL CONCEPTS

THURSDAY, JULY 18, 1974

U.S. SENATE,
COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES,
Washington, D.C.

The committee met, pursuant to recess, at 9:35 a.m., in room 235, Russell Senate Office Building, Senator Barry M. Goldwater presiding.

Present: Senators Goldwater and Bartlett.

Also Present: Robert F. Allnutt, staff director; Craig M. Peterson, chief clerk/counsel; James J. Gehrig, Glen P. Wilson, Craig Voorhees, Jerry Staub and Gil Keyes, professional staff members; Mary Rita Robbins, clerical assistant; Charles F. Lombard, minority counsel, and Anne Kalland, minority clerical assistant.

Senator GOLDWATER. The meeting will come to order.

Senator Moss, the chairman of the committee, is detained at a party caucus and cannot be here, so I will get the show on the road.

This is a resumption of the hearings on Advanced Aeronautical Concepts that we started the other day. We have five witnesses. It is my understanding that this is the first time in over 30 years that a committee of Congress has received testimony on the subject of lighter-than-air vehicles. I hope we would not have to wait until the year 2004 for the next set of hearings.

I might say that I have been very surprised at the amount of interest that has been shown across this country in this subject. When we first talked about it, I thought the last believers in dirigibles disappeared in Lakehurst many many years ago but as I mentioned the other day, I think I have been made an honorary member of about five lighter-than-air clubs already and in as much as balloon rating is the only rating I do not have, I am going to have to go out and get one of those.

Our first witness is Mr. Gordon Vaeth, director, system engineering, National Environmental Satellite Service. You may proceed.

[The biography of Mr. Vaeth follows:]

BIOGRAPHY OF J. GORDON VAETH, DIRECTOR, SYSTEMS ENGINEERING, NATIONAL ENVIRONMENTAL SATELLITE SERVICE, NOAA

J. Gordon Vaeth graduated from New York University in 1941. During World War II, he served as a ground officer with airship commands of the Atlantic Fleet and acquired a background in lighter-than-air operations which he seeks now to apply to the revival of the very large airship. Following the war, he became a member of the ONR stratosphere balloon projects HELIOS and SKYHOOK and later headed the New Weapons and Systems Division of the U.S. Naval Training Device Center. His specialty at NTDC was flight and missile performance simulation. Author of the first popular book published in this country on high-altitude rocketry and spaceflight, his writings in the 1950's are among the earliest in the literature of astronautics. He was briefly a mem-

ber of Project Orbiter which preceded Vanguard. As a member of the Technical Staff of the Advanced Research Projects Age he was responsible for technical matters pertaining to Man-in-Space. A ntributor on airships to the Encyclopedia Britannica, he has authored six books, including GRAF ZEPPELIN, and over 100 articles and papers, many of which deal with the applications of lighter-than-air technology. An Associate Fellow of the American Institute of Aeronautics and Astronautics, he was one of the organizers of the "Helium Horse" session of the AIAA's 1974 Annual Meeting. A member of the British Interplanetary Society, Lighter-Than-Air Society, and the U.S. Naval Institute, he is a biographee of WHO'S WHO IN AMERICA.

STATEMENT OF J. GORDON VAETH, DIRECTOR, SYSTEM ENGINEERING, NATIONAL ENVIRONMENTAL SATELLITE SERVICE, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Mr. VAETH. Thank you, Senator. Mr. Chairman, on behalf of the increasing number of individuals in Government, industry, and the academic community who believe that lighter-than-air vehicles offer a way to a more productive aeronautical future, I want to thank this committee for the opportunity to appear before it to discuss the potential offered by very large airships or dirigibles. My appreciation is made all the greater by the fact which you have just mentioned, that this is the first time that testimony on this subject has been invited by a committee of the Congress in probably well over a quarter of a century.

The comments and recommendations that I have to offer are based on my experience as a member of naval airship commands during World War II and, more recently, on my awareness as a governmental technologist of what might be achieved by applying aerospace progress in materials, structures, and power plants to the improvement of airship safety, performance, and utility. My views are my own and do not represent those of the National Environmental Satellite Service of NOAA, which I am privileged to serve as director of system engineering.

Exemplified by America's Akron and Macon, Britain's R–100 and R–101, and Germany's Graf Zeppelin and Hindenburg, large airships were abandoned, presumably forever, in the 1930's. Now, suddenly, we are seeing an international revival of interest in returning them to the sky. In England, a 25-million-cubic-foot cargo-carrying ship—the Hindenburg, by contrast, was 7 million cubic feet—possessing a payload greater than 600,000 pounds has been the subject of a study by the Cranfield Institute of Technology. Airfloat Transport Ltd., of London is proposing a 46-million-cubic-foot vehicle for a similar purpose. And Shell International is reportedly pursuing a 100-million-cubic-foot design to transport natural gas. In the developing countries, the dirigible is increasingly seen as a means to bring transportation to the interior where roads, railways, and air facilities are nonexistent and where they would be extremely costly to provide. The airship's ability to operate quite independently of ground facilities and to move with great flexibility in and out of essentially unprepared clearings in jungle and hinterland areas has excited the interest not only of a number of specific governments in Africa and South America, but also of the Organization of American States, the Inter-American Development Bank, the World Bank, and the Organization for Economic Cooperation and Development. In the United States, NASA's forthcoming airship feasibility study and the Lighter-Than-Air Workshop, to be held in September under

NASA, Navy, and Department of Transportation sponsorship, are, of course, helping generate this renewed interest, as is, of course, the professional exposure being given to the subject by the American Institute of Aeronautics and Astronautics.

Just why is the airship attracting such attention? The reasons have a lot to do with the energy, environmental, and transportation problems of today. The dirigible is an energy-saver for one thing. Being lighter than air, it need expend no propulsive energy to overcome gravity, using its engines only to move and maneuver. Compared with jet aircraft, its fuel requirements are low. Large, slow-turning, counter-rotating, stern-mounted propellers can make it exceptionally quiet, and it can be driven by environmentally desirable closed-cycle powerplants.

It can be sized to carry payloads of up to 1 million pounds with almost no limitation on payload dimension. It can transport extra large, fully assembled structures and equipment and do so over intercontinental distances. Operating as a VTOL, it makes possible delivery of those loads to open areas or fields without heavy-duty runways or other costly and ecologically disturbing site preparations. By hovering over pick up and delivery points, it holds promise of being able to load and unload items without actually landing, winching cargo up and down while maintaining position with thrust vector control and buoyancy management. Alternatively it might use a type of shuttle craft between itself and the ground. The hybrid Aerocrane, a combination balloon and helicopter now being studied under a Navy contract, and described by the Navy to this committee on Tuesday, could be just that vehicle. Whatever the pick up and delivery technique actually used, the ability of such a merchant ship of the sky to provide long distance point-to-point transport of cargo without landing could radically change our concepts for moving things by air.

The airship's potential for commerce has drawn to it a number of would-be users. John R. Norton III of Phoenix, Ariz., a major produce grower, is typical. In terms of only lettuce, he ships 600,000 pounds of it every day. Concerned over the shortage of refrigerated railroad cars and by the problems of rail service, concerned, too, over the possible effects of fuel shortages, reduced highway speeds, and rising costs of truck transport, he sees in the 100 mph airship a vehicle to overcome and overfly the problems of domestic surface transportation. He also sees it as a means to develop markets overseas.

Stephen J. Keating, program manager, Airborne Heavy Lift Transportation Systems, for combustion engineering of Windsor, Conn., is another. At the "Helium Horse" airship session of the annual meeting of the American Institute of Aeronautics and Astronautics this past January, his remarks concerning the transportation of large, preassembled, nuclear reactor components to inland destinations made an exceptionally strong case for the airship. In view of the goal of making the United States self-sufficient in energy, his statement of the transportation needs facing the builders of nuclear electrical generating plants urgently deserves a solution, be it by airship or other means.

Nuclear energy brings to mind nuclear propulsion and here the dirigible really offers a unique opportunity for a genuine quantum jump. Airships, being displacement vessels, resemble surface ships

and submarines far more than they do airplanes. As mentioned earlier, their energy needs are low. Thus, for nuclear propulsion, they need less powerful reactors and less shielding. Also, by virtue of their size, radioactively "hot" elements can be effectively isolated and cushioning and shock-absorbing mounting systems provided to safeguard against a nuclear mishap in event of a crash.

The nuclear propulsion of both aircraft and spacecraft has proven an elusive goal. Considering the comparative simplicity of adapting a nuclear engine to an airship, why not do so and use it as an airborne testbed (flying mainly over the ocean) to develop the technology and operating experience needed to achieve these long-standing, promising, yet unfulfilled applications of atomic power?

The value of a nuclear-propelled dirigible is not limited to just a testbed application however. Naval Research Laboratory memorandum report 2463 of July 1972, for example, gives the payload for any range of a nuclear-driven 22-million-cubic-foot airship at 655,000 pounds! This sort of performance should be of special interest to the Defense Department's Military Airlift and Military Sealift Commands, particularly in view of the dirigible's already-cited ability to operate without runways or prepared sites. I might add that the Office of the Navy Comptroller has recently taken an interest in this airlift-by-airship concept.

Unlimited range implies unlimited endurance, each within human and practical limits, of course. From this standpoint, the ability of such an airborne vehicle to maintain continuous, unrefueled, and weeks-long station over the remotest of ocean areas in antisubmarine surveillance is particularly timely and important. Able to deploy and tow what would probably be the largest passive sonic arrays ever used by a moving naval unit, able to do so without generating the hull and screw noises that handicap surface ships in their antisubmarine listening, able to maintain a hovering "silent presence" in developing an underwater contact, able to chase after the contact at 100 mph or better without regard for sea state, and able to carry out an attack either itself or by the aircraft or RPVs (Remotely Piloted Vehicles) that it could carry, launch, and recover, the indefinite range, indefinite endurance, antisubmarine, nuclear-propelled airship could revolutionize naval tactics and thinking.

Mr. Chairman, I would like to invite the committee's special attention to this naval application of the dirigible. Evaluation of the future usefulness of the airship is being tied much too much, in my opinion, indeed almost entirely, to its commercial uses. This naval mission, which is also possible with conventional propulsion and refueling at sea, is an application to be decided more by military considerations than by such factors as ton-mile costs. I strongly urge that this airborne version of the Sea Control Ship, intended to augment the capabilities of the surface version, be examined in depth.

I would like to depart from my prepared statement at this point and comment, as I feel I must, upon Vice Admiral Moran's testimony on Tuesday that airships, blimps being the term used, have no foreseeable usefulness for antisubmarine warfare. The reason he gave was the airship's alleged inability to make headway against the wind in pursuing a high speed submerged submarine. Frankly, if he was thinking of pitting a 1940 vintage nonrigid airship or blimp

against a 1974 attack or ballistic submarine, I would be the first to agree with him. But what we are talking about here is an airship of the 1970's and 1980's, capable of flank speeds twice that possible in World War II and carrying on board aircraft and RPV's to execute an attack if the airship for some reason is itself prevented from doing so. In replying to the question put to him on airships and antisubmarine warfare, I am confident that Admiral Moran was not thinking of airship capabilities in this modernized context.

In other and less controversial areas, airships have still other possibilities, for geophysical exploration, for oceanic work, for natural disaster relief, for environmental monitoring, and for diplomatic initiatives leading to new applications-oriented programs of international cooperation. In this latter regard, one might visualize the airship as a partner of the Earth resources satellite, the spacecraft identifying the location of these resources for developing countries and the dirigible providing the means of access to them.

To make use of the benefits offered by large dirigibles, I feel we should keep three things in mind:

First, that the last such ship, the *Graf Zeppelin II*, sister of the *Hindenburg*, was built 35 years ago. The subsequent aerospace progress has never been applied to this type of vehicle. And in the meantime, the building of large airships has become almost a lost art. In a sense, we must begin again and, in a sense, never has there been a greater opportunity for aerospace technology application and transfer.

Second, that the uses I have been describing here require the development, testing, and proving of equipment and operating techniques which are achievable but do not now exist.

Third, that lacking any experimental airships to generate actual technical data, studies of lighter-than-air capabilities, no matter how competently undertaken, must remain theoretical and their results subject to confirmation (or correction) in the real world of flight.

Based on these factors, Mr. Chairman, I would make this specific recommendation to the committee: That a "proof of concept" flight program, involving construction and operation of a small to moderate sized experimental testbed airship, be authorized for NASA.

I would propose that the approach be similar to that of the Rotor Systems Research Aircraft program in which, as I understand it, one helicopter fuselage is used to experiment with a variety of exchangeable rotor systems. I visualize a modular airship car, which can easily be changed in size and configuration to accommodate various engine, landing gear, ground handling, and command and control arrangements. To it would be fitted a variety of exchangeable airship hulls, of differing form factor, differing volume, and of differing materials and construction, including nonrigid, semirigid, and even rigid design. Here would be a vehicle to provide test data on forward control surfaces, stern propulsion, fin-mounted powerplants, even the possibility of propulsion by steam. With it the techniques of hovering, buoyancy management, and thrust vector maneuvering could be developed. By means of it, new mooring techniques could be tried out and the advantages of hybrid designs investigated. Hybrids, that is to say, airships shaped to generate sizable aerodynamic lift from their movement through the air as well as aero-

static lift from their helium, are a particular promising design concept that could impact heavily virtually every lighter-than-air application that I have touched upon this morning.

To begin with, I would suggest an experimental vehicle with a useful lift of about 30 tons. It could be flying within 3 years for an approximate cost of $30 million spread over 2 or more fiscal years. So important in my opinion is the airship to the potential solution of our current energy and other transportation problems that I would further recommend, Mr. Chairman, that the necessary preparation and preliminary design be started this year.

I hope that the members of this committee and staff and my friends and colleagues at NASA who are here in this audience will not think me too presumptuous for informally volunteering my opinion concerning NASA programing and funding. I feel, however, that having been given the privilege of appearing before you that I would fall short of my obligations if I did not make a specific and concrete recommendation.

This concludes my testimony.

I have several illustrations of possible future airship designs (Figures 1–4) and a bibliography of recent relevant literature which, with the committee's approval, I would like to submit for the record. Thank you, Mr. Chairman.

Senator GOLDWATER. If you will submit those.

[The material referred to follows]

Possible airship configurations of the future. Figure I shows a 50-million-cubic-foot cargo-carrier, moored on a turntable at its headquarters base with an inflatable hangar in the background. Figure II is a nuclear version of a passenger ship (the reactor details have been exaggerated). Figure III depicts a natural disaster relief mission being carried out without benefit of airport or prepared facilities. In figure IV, two environmental airships are at work, making atmospheric and marine observations and, in the case of the lower ship, engaging in the cleanup of an oil spill.

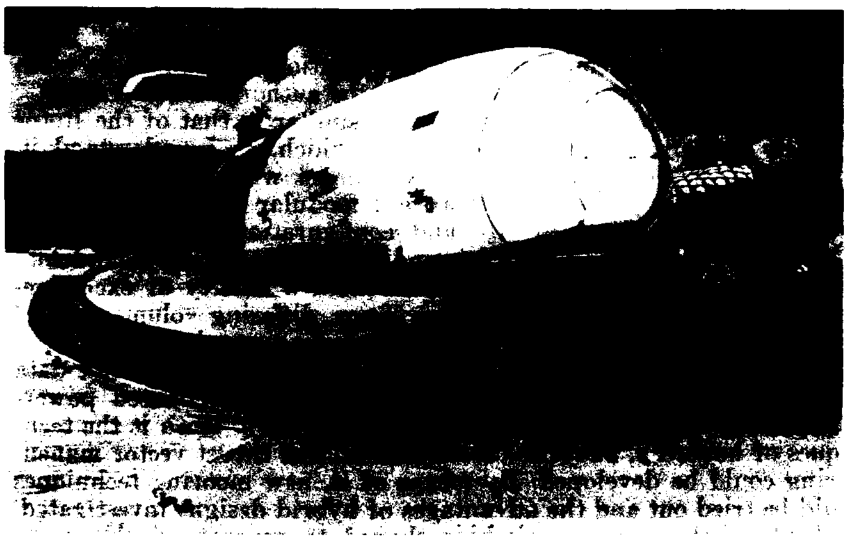


FIGURE 1. A 50-million-cubic-foot cargo-carrying airship, moored on a turntable at its headquarters base with an inflatable hangar in the background.

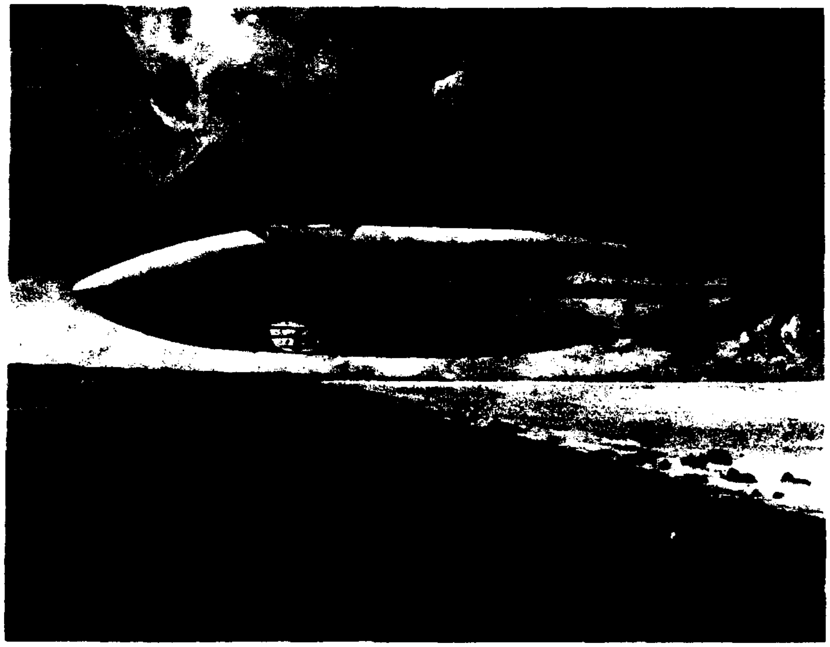


FIGURE 2. A nuclear version of a passenger airship (reactor details have been exaggerated).

FIGURE 3. A natural disaster relief mission being carried out by airship without benefit of airport or prepared facilities.

38-266 O - 74 - 7

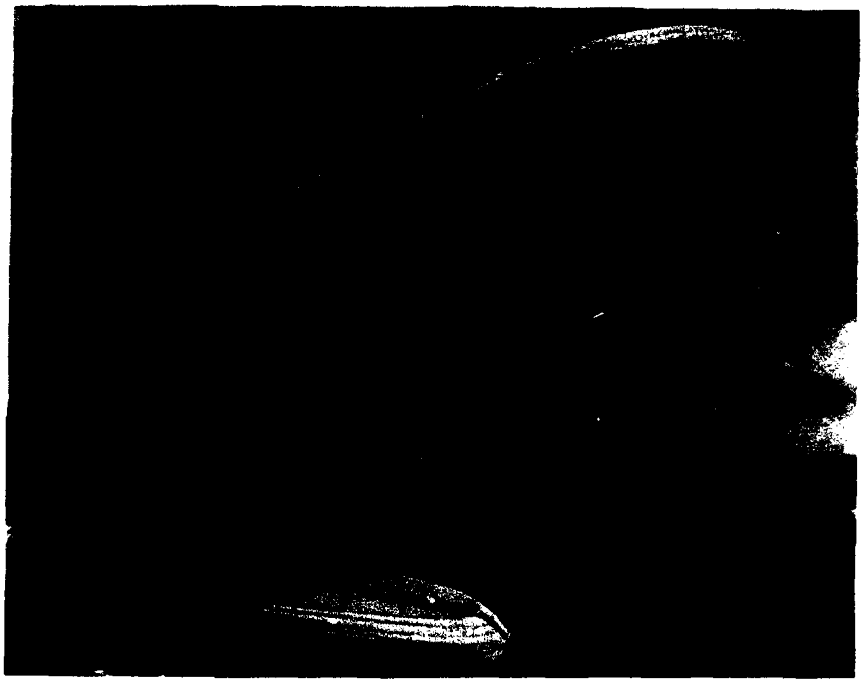


FIGURE 4. Environmental airships at work, making atmospheric and marine observations and, in the case of the lower ship, engaging in the cleanup of an oil spill.

SELECTED BIBLIOGRAPHY OF AIRSHIP BOOKS, REPORTS, AND ARTICLES PUBLISHED SINCE 1972

The Airfloat Project: Proceedings of a One Day Symposium, Multi-Science Publishing Co. for Airfloat Transport Ltd (The Old Mill, Dorset Place, London E15 1DJ), 1972

Stevenson, Robert E. and Terry, Richard D., "Oceanography from a Blimp," Buoyant Flight, March/April 1972

Morse, Francis, "Cargo Airships: a Renaissance?", Handling & Shipping, June 1972

Clements, E. W. and O'Hara, G. J., "The Navy Rigid Airship," NRL Memorandum Report 2463, Naval Research Laboratory, July 1972

Jones, Trevor, "Airship Project for Natural Gas Shows Early Promise," Seatrade, August 1972 (a British publication)

Morse, O'Hara, Pavlecka, Stehling and Vaeth, "Dirigibles: Aerospace Opportunities for the '70s and '80s," Astronautics and Aeronautics, November 1972

Abbott, Patrick, Airship: The Story of R. 34 and the First East-West Crossing of the Atlantic by Air, Charles Scribner's Sons, New York, 1973

Brooks, Peter W., Historic Airships, New York Graphic Society, Greenwich, Connecticut, 1973

Hook, Thom, Shenandoah Saga, Air Show Publishers, Ferry Farms, NAPO, Annapolis, 1973

Jackson, Robert, Airships, Doubleday & Company, Inc., Garden City, New York, 1973

McPhee, John, The Deltoid Pumpkin Seed. Farrar, Straus and Giroux, 1973

Robinson, Douglas H., Giants in the Sky: A History of the Rigid Airship, University of Washington Press, Seattle, 1973

Coughlin, S., An Appraisal of the Rigid Airship in the UK Freight Market, Centre for Transport Studies, Cranfield Institute of Technology, Cranfield, Bedford, England, March 1973

Sonstegaard, Miles H., "Transporting Gas by Airship," Mechanical Engineering, June 1973
Vaeth, J. Gordon, "Dirigibles: Naval Vehicles for Tomorrow," Sea Power, June 1973
Hunt, Levitt, Morse, Stehling and Vaeth, "The Many Uses of the Dirigible," Astronautics & Aeronautics, October 1973
Stehling, Kurt R. and Vaeth, J. Gordon, "A Compelling Case for the Helium Horse," NOAA Magazine, October 1973. Reprinted with updated material in Naval Aviation News, May 1974
Alexander, Tom, "A New Outbreak of Zeppelin Fever," Fortune, December 1973
The Helium Horse: Air Transportation for Tomorrow, American Institute of Aeronautics and Astronautics Recorded Lecture Series, 2-hour recorded program available in cassette form, 1974
Seeman, Harris, Brown, and Cullian, "Remotely Piloted Mini-Blimps for Urban Applications," Astronautics and Aeronautics, February 1974
Vaeth, J. Gordon, "The Airship Can Meet the Energy Challenge," Astronautics and Aeronautics, February 1974
Note: In addition, see Buoyant Flight, published bimonthly by the Lighter-than-Air Society, 1800 Triplett Boulevard, Akron, Ohio 44306, and Inside the Control Car, issued by Roy D. Schickedanz, 910 Sherwood Lake Drive, Schererville, Indiana 46375.

Senator GOLDWATER. You mentioned that the Hindenburg was a 7-million-cubic-foot aircraft and one of the oil companies is looking at a 100 million cubic foot ship. What was the size of the Hindenburg? How long was it?

Mr. VAETH. The Hindenburg was 803 feet long and 135 feet in diameter.

Senator GOLDWATER. What would be the dimensions of a 100-million-cubic-foot aircraft?

Mr. VAETH. The reports I have seen on that should it about 1,800 feet long.

Senator GOLDWATER. Is that design depicted in one of your illustrations?

Mr. VAETH. No, sir. The pictures you have are artist concepts only and not based on any specific designs. The figure you have in front of you is a proposed 50 million cubic footer.

Senator GOLDWATER. You say that lacking actual flight data even the best studies will only be theoretical and their results questionable. What actual data do we have to help give us a handle on airship economics and practicability?

Mr. VAETH. The data we have, which are, incidentally, very encouraging, are data from the German Zeppelin operations of the 1930's. Between about 1930 and 1937, the Germans operated the Graf Zeppelin in a regularly scheduled trans-Atlantic passenger, cargo, and mail service between Germany and Brazil. The service began in the spring and ran until December. The commercial arrangements for it were made through the Hamburg-American Line. The Graf Zeppelin during its 9-year flying lifetime made a total of 590 flights, flew over a million miles, crossed the ocean 144 times, and spent 17,000 hours in the air. The success of this service is perhaps best attested to in the form of a Zeppelin hangar, which still stands today 25 miles south of Rio and was constructed by the Brazilian Government as an indication of the future which it felt the airship had at that time.

The Graf Zeppelin was a very successful but inefficient airship because its volume and shape were dictated by the size of the largest hangar left in Germany after World War I in which to build it.

The Hindenburg was an entirely different situation. Its volume was about twice that of the Graf Zeppelin. The Hindenburg in one year of operation, 1936, made 10 round trip flights across the North Atlantic, while covering 75 percent of its total cost by revenue. Twenty percent of its passenger accommodations were occupied by non-paying VIP's and persons making the flight for training. The Zeppelin Co. projected that if another three to four ships were added to the service, it could look forward to a 7 percent return on its investment.

Unfortunately the Hindenburg, as we all know, burned at the start of its second season of operation. Stories of sabotage notwithstanding, the fire was caused, in my opinion, by an electrical discharge triggered off, believe it or not, by a technological improvement. The Hindenburg had a new and "improved" type of aluminized dope on its cloth outer cover. It was found after the accident that this dope had the effect of considerably changing the electrical properties of that cover, probably setting the stage for the generation of a spark in the thunderstorm atmosphere at Lakehurst that May 6, 1937.

Be that as it may, the Hindenburg and Graf Zeppelin provided a reliable commercial service and with modern technology we can look forward to a resumption of even better routine commercial operations by large airships.

Senator GOLDWATER. What was the cruising speed?

Mr. VAETH. The cruising speed of the Hindenburg, Senator Goldwater, was 77 miles per hour. Maximum speed was about 82.

Senator GOLDWATER. What do you envision with the new ones?

Mr. VAETH. A minimum cruising speed of 100 miles per hour and top speeds of 125 to 150.

Senator GOLDWATER. You mentioned new diplomatic intiatives with the airship. What do you have in mind?

Mr. VAETH. Two things, sir. One would be a cooperative airship program with the Soviet Union; the other a cooperative program with the developing nations of the Third World. It is little remembered today, but the Soviets have a long history of airship activity. They flew airships, helium-filled airships, as far back as the 1930's. For a number of years, a Soviet dirigible, the V–6, held the world's endurance record for airships of any kind, a record of 130 hours unrefueled.

There are continuing reports in the Soviet press of interest in using airships to develop the Siberian interior, bringing large preassembled heavy equipment in and bringing natural resources out. An article in a Soviet magazine approximately 2 years ago said, I do not know how correctly, that a total of 14 Soviet agencies, including several ministries, favored the building of airships for this purpose. There would thus seem to be interest there, and if we have interest here, some type of cooperative program might very well be worked out.

As for the developing countries of the Third World, I have been told that at this moment there are requests from three different South American countries in the hands of the Inter-American Development Bank asking that airships be investigated as a means to solve their internal transportation problems. I would hope that this interest, not generated by us but generated by those countries themselves, might lead also to some type of cooperative program. I would hope, Mr. Chairman, that the United States and not some other country would be the one to develop and utilize airships to assist the developing countries of the Third World.

Senator GOLDWATER. What are the most acute technical or operational problems you foresee in bringing back the dirigible?

Mr. VAETH. The first one is keeping the airship off the ground. If we are talking about a dirigible 1,000 feet long and 250 feet wide, we are also talking about a very large sail when the ship is being handled on the ground. I believe that the airship should be kept airborne as much as possible to minimize the ground handling problem. Which is why I very much favor, as do others, the idea of the airship unloading and loading without landing, by winching or by bringing cargo or passengers aboard by some type of shuttle craft.

Commander Jack Hunt, who, for instance, in the 1950's flew a Navy nonrigid for an unrefueled record of about 260 hours, is of the opinion that one of the best uses for airships is to fly them round-robin around the North Atlantic, coming up the eastern seaboard, going across to Europe, going down from Europe to North Africa and back across and that that airship, possibly nuclear propelled, would fly this route while its cargo would be airlifted on and off through the shuttle arrangement I have mentioned. In summary, the most major problem, as I see it, is to minimize the ground handling.

The second most important is to ensure the adequacy of trained personnel. Many of the accidents to airships in the 1920's and 1930's can be laid directly to lack of experience. Tuesday the Committee heard described the value of flight simulators. Flight simulators will have an important role in training crews to handle large airships. Certainly one is not going to build a 50-million-cubic-foot airship and simply say, "there she is, boys, take her up." Much training will be required ahead of time in the air in training ships and on the ground in simulators.

Senator GOLDWATER. One more question. The mission model for the space shuttle foresees 770 flights in the decade of the 80's. As you know, two solid rocket motors will be used on each flight. These rockets are 149.1 feet long, 146 inches in diameter and weigh about 179,600 pounds empty. They will be jettisoned into the Atlantic or Pacific depending on where the flight originates. In other words, over 1,500 solid rocket casings will have to be retrieved at sea for refurbishment and reuse.

Do you consider this a suitable mission for lighter-than-air?

Mr. VAETH. Not only suitable, but a natural.

First, I assume that a prime objective would be to get those boosters out of the corrosive sea water environment as fast as possible. There-

fore, the first step would be to deploy booster recovery vehicles that can reach the sites of these expended boosters as rapidly as possible—and airships can get there faster than surface ships.

Now, assuming that we have a surface ship and an airship competing to retrieve such a booster, if the sea state is high or if a heavy sea is running, there may be a considerable problem on the part of the surface craft in lifting out the booster, which according to the dimensions, and which you just mentioned, sir, are certainly formidable. The surface ship will probably have difficulty bringing it on board without smashing the rocket casing against the side of the rolling and pitching vessel. There is a definite advantage to the airship in this case because the airship can lift vertically and, once it removes the expended booster from the water, it is able to hoist it directly up to the ship itself. It need not, incidently, take it inside. It can simply suspend it beneath the hull which is relatively unobstructed.

So I think, sir, this would be a very logical and very cost effective application for the very large airship.

Senator GOLDWATER. Thank you very much, Mr. Vaeth, for your presentation and your answers.

Thank you very much.

Mr. VAETH. Thank you.

Senator GOLDWATER. We will now hear from Prof. Joseph Vittek, Assistant Professor, Department of Aeronautics and Astronautics, MIT. Go right ahead and start.

[The bibilography of Professor Vittek follows:]

BIOGRAPHY OF JOSEPH F. VITTEK, JR., ASSISTANT PROFESSOR OF AERONAUTICS AND ASTRONAUTICS, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

A member of the Massachusetts Bar and of the faculty in the M.I.T. Department of Aeronautics and Astronautics, Mr. Vittek offers courses in the legal, regulatory and public policy aspects of transportation. He received his Jurisprudence Doctorate from Suffolk University Law School, graduating at the top of his class. Mr. Vittek also received an LL.M. from the Harvard Law School where he specialized in governmental administrative and regulatory processes. His undergraduate degree is a B.S. in Mathematics from M.I.T.

Mr. Vittek is also Associate Director of the M.I.T. Flight Transportation Laboratory and is involved in studies of various aspects of the air transportation industry (transportation economics, demand modeling, noise prediction and reduction, air traffic control, transportation data management systems, etc.). These studies are funded by such government agencies as NASA, DOT, FAA and the U.S. Army.

In addition, Mr. Vittek has held the following technical positions: 1969–70 Director of Software, M.I.T. Draper Laboratory's Deep Submergence Project; 1966–69, Project Manager for Software, first manned Apollo Mission; 1963–66, Flight Test Engineer, Honeywell Aerospace; and 1962–63, Systems Analyst for M.I.T. Draper Laboratory.

Professional memberships include the Chairmanship of the American Institute of Aeronautics and Astronautics' Lighter Than Air Subcommittee. Mr. Vittek also serves on the Associate and Advisory Committee of the American Bar Association's Standing Committee on Aeronautical Law and served on the Transportation Planning Council for the City of Newton, Massachusetts. He is also admitted to the Federal Bar for the District of Massachusetts.

He has written several recent articles and reports on Lighter Than Air vehicles, air service to small communities, aircraft requirements for low density markets and airport noise abatement and control.

STATEMENT OF JOSEPH F. VITTEK, JR., ASSISTANT PROFESSOR, DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS, MIT

Professor VITTEK. Thank you. I have submitted prepared testimony for the record which I will leave stand as it is. I would prefer this morning to make my presentation based on some informal remarks and the use of some vugraphs that the Army has been nice enough to assist me in showing.

I think from Mr. Vaeth's talk we can tell that lighter-than-air certainly has a great deal of potential and that it also has its problems. There is very little doubt that modern technology can solve many of these problems. The issue in my mind becomes whether or not the cost of that technology can be recovered to such an extent that it would make the lighter-than-air concept economically sensible.

For any new mode of transportation to succeed, it has to be better in some way than the transportation modes it is supplanting. Clearly the airship, because of its large payload, is better than a truck. It is better than rail or barge to the extent that it does not have to follow a particular route. It is better than an ocean-going vehicle because it can travel faster. It can come inland directly without stopping at a port. And it can potentially carry more in a payload sense than a large airplane while not requiring as large airport facilities. So, at least in theory, there are advantages over other modes. These advantages lead to a number of potential applications and, as Mr. Vaeth has covered many of them, I will not go into them in detail.

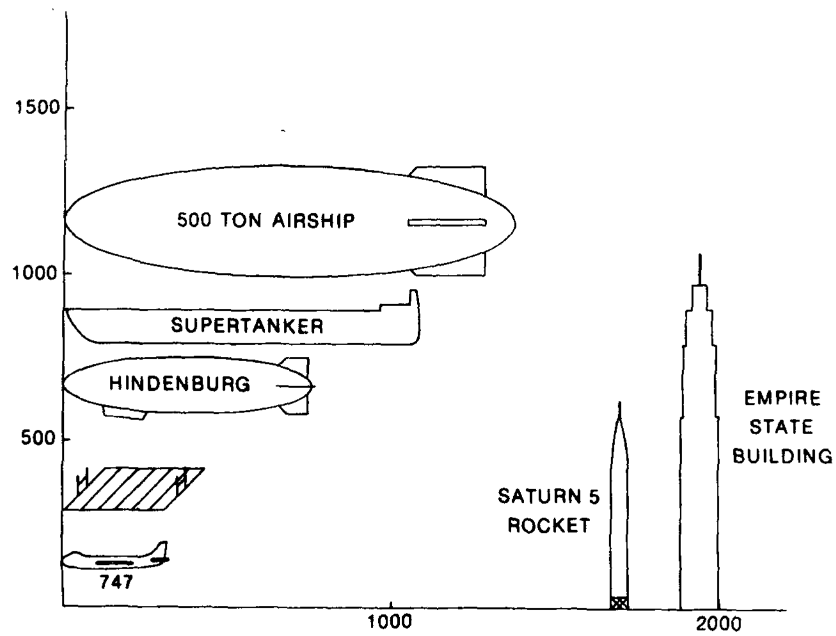


FIGURE 1

I will instead go on to some of the problems associated with the airship. Most of these problems are related to the size of the airship.

Figure 1 indicates the relatvie size of a 500-ton airship, which is certainly within the range of those discussed today; a super tanker; the Hindenburg; a football field and a 747. As you can see, the airship is very large and its size does create ground handling problems and certain airborne problems that will be mentioned shortly.

Now, although the lighter-than-air ship can hover, discharge its traffic, et cetera, as Mr. Vaeth discussed, it also needs a ground base at some point. Because of the necessity for anchoring it against the wind and for providing flexibility for wind direction, this can consume a fair amount of land.

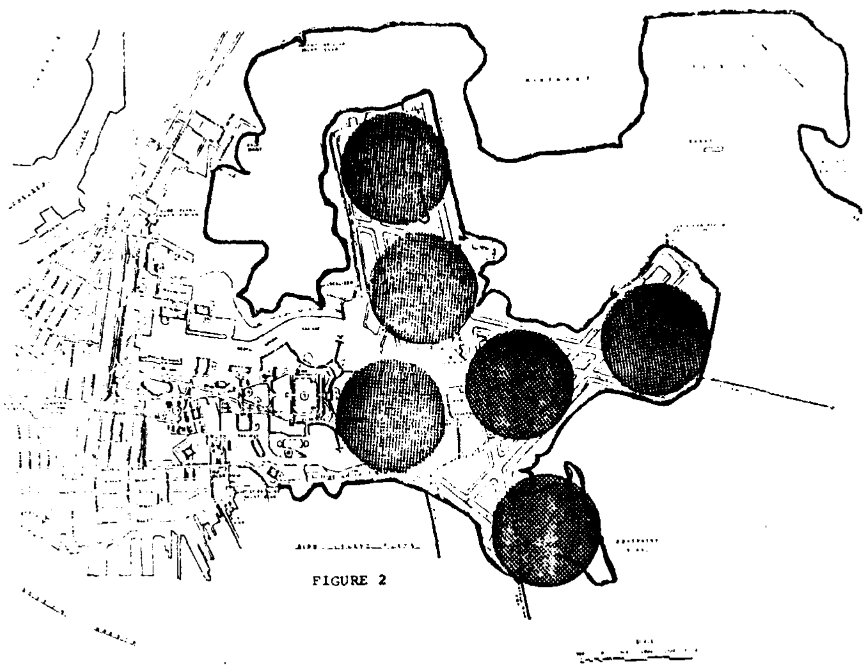


FIGURE 2

Figure 2 shows the ground requirements for six 1,000-foot dirigibles imposed on Logan Airport in Boston. As you can see, the ground requirement can be extensive. I have used an existing airport for comparison. However, because the primary mission may be freight, it can also be handled outside the city in less expensive ground areas. Nonetheless, we can not ignore that there is a significant ground requirement for the airship.

A major problem in the past has been ground handling of the airship. Figures 3, 4, and 5 show the large crew requirements that were necessary in the old dirigibles. They were pushed out by hand, held by hand. Three or four hundred people were necessary to keep them on the ground, as Mr. Vaeth pointed out.

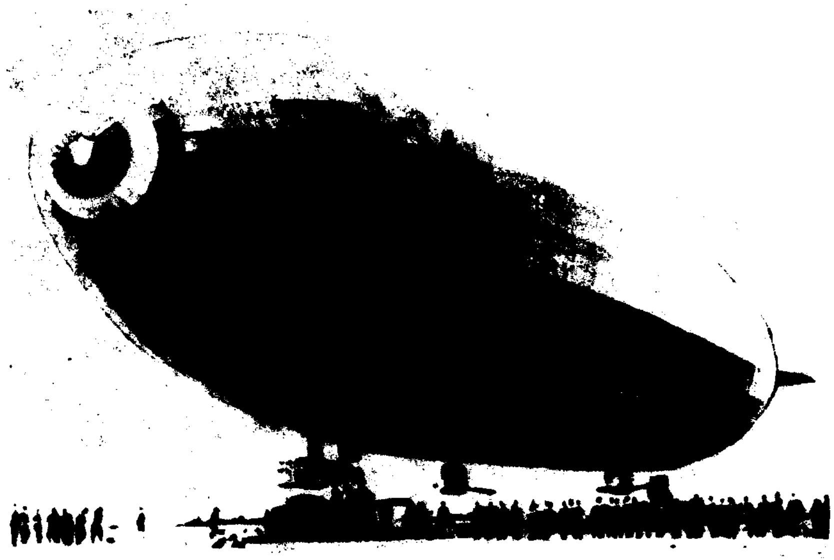


FIGURE 3

NA & SM/SI

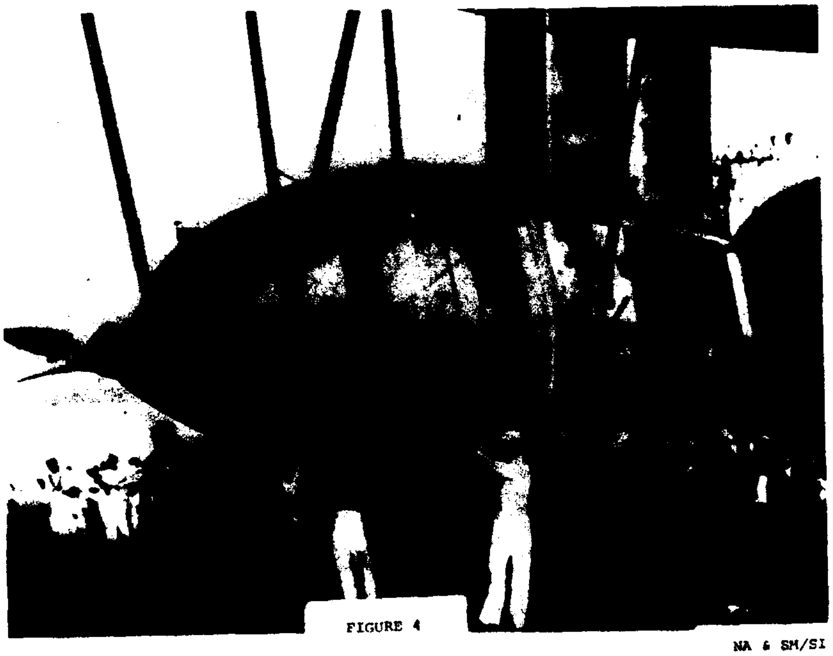


FIGURE 4

NA & SM/SI

FIGURE 5

NA & SM/SI

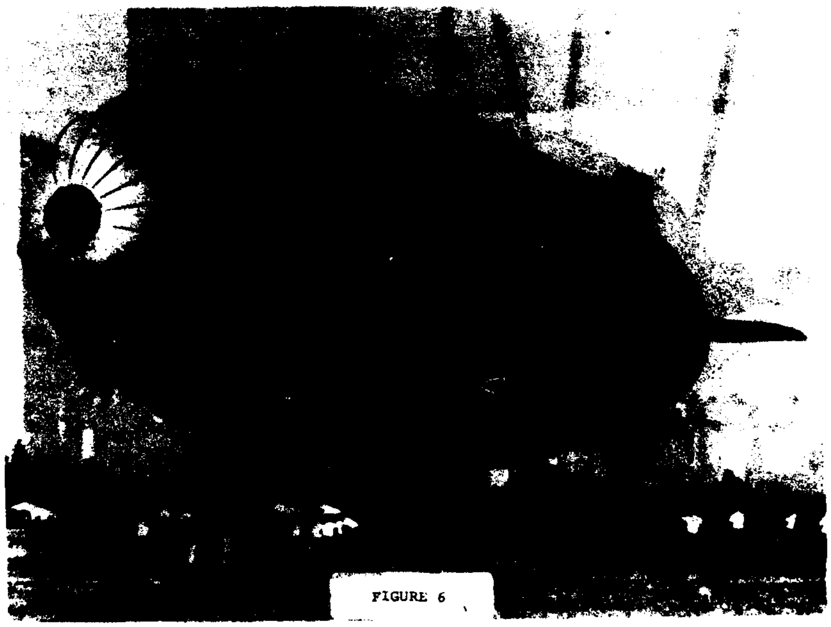


FIGURE 6

FLYING

As Figure 6 shows, even today the 200-foot Goodyear blimp, which is fairly small, requires a ground crew of about 10 people to bring it down. Also, the Goodyear blimp is so dependent on its ground handling crew that it is often required to linger in the air waiting for the crew to catch up with it, erect its mast and bring it down.

Another problem is ballasting. An airship picks up cargo and discharges ballast—or discharges cargo and picks up ballast. In either case, it always transfer one for the other. Its ballasting problem could be severe if it were in an isolated area where it wanted to discharge cargo.

Another problem area is susceptibility to damage in ground handling. Figure 7 is a picture of the Shenandoah which tore off its

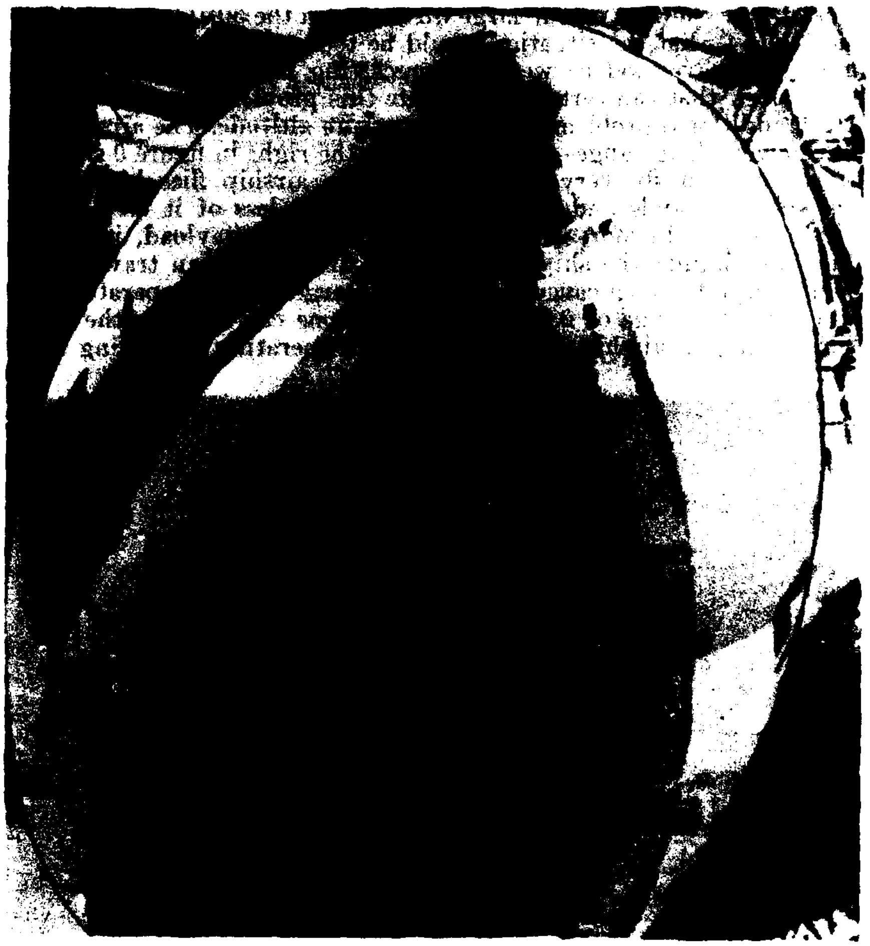


FIGURE 7

mast in Lakehurst. I believe it took several months to repair the damage.

Figure 8 shows the very recent accident to the Goodyear blimp as it was being pulled out of its hangar at Houston last year. It bumped up against the hangar door and was laid up for 4 to 6 weeks for repairs.

Another problem area is helium. Certainly by using helium we avoid hydrogen's explosiveness. However, helium is not an element that we can create. It is found in our natural gas wells in this country and we have the best supply in the world, but a large scale program will require a lot of helium and I don't know, although I am sure some of our people from the Department of Interior do, just how large our helium supply is. Since helium has replaced hydrogen, a major fear is no longer fire but breakup in violent weather. This was clearly the fate of our large dirigibles in the 30's. It is very difficult to say what the situation would be today although we do know more. We have modern weather forecasting techniques and modern technology that can certainly alleviate this problem.

An additional problem is that of pressure altitude. The airship can have a very long range—as the curve on the right in figure 9 shows—if it does not fly very high. But as the airship flies higher, the gas itself expands and has to be released or less of it used so the airship can gain more altitude. This offsets the payload, including fuel. The higher the ship flies, the less distance it can travel. As a compromise between cargo and altitude, large airships operate somewhere in the range of 2,000 feet. I think one can imagine the problems facing an airship commander today, operating something 1,400

FIGURE 8

World Wide Photos

FIGURE 9

feet long, at 2,000 feet altitude, cruising through our airways. This is something that has to be considered.

There are technological solutions to many of these things. Perhaps the air handling and ground handling problems both can be solved through applications of modern inertial sensors. I have shown in figure 10 that, if an airship is designed with appropriate sensor

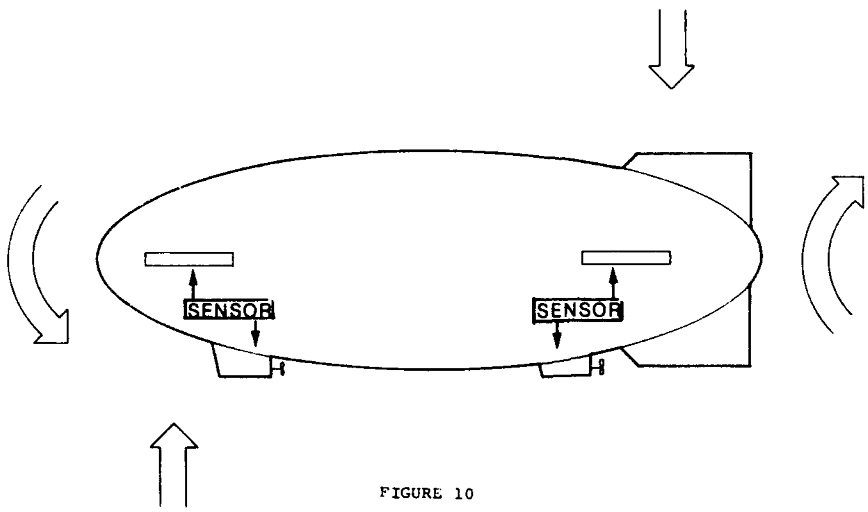


FIGURE 10

packages, rotational forces, stresses and strains could be detected very quickly and fed back to control surfaces and engines and counter-acting forces could be applied. We know how to do this from the Apollo program. It is a direct application of the same types of things.

Also, television can be mounted in the front, back, or wherever it is needed by the crew so they can perhaps avoid some of these ground handling problems, have better visibility, et cetera.

Weather forecasting is certainly improved. We have computer design methods (also developed for the space program) for stronger structures and lighter weights at the same time using modern materials. The same type of thing can be applied to airships.

So, in short, I think the technology is available to conquer many of of these problems. However, the issue, as I said at the beginning, is whether or not the cost of that technology, when incorporated into the airship, allows us an economically viable vehicle.

Now, a lot of special applications can only be performed by an airship. However, to be a commercial success, airships must capture a certain amount from existing transportation markets. I am going to stress the commercial side; Mr. Vaeth pointed out the importance of the military. Military missions can be evaluated in a very similar way: See if the mission is being provided now; how it is being provided—how a helicopter or ocean craft is being used; the relative cost of that versus an airship; and, to the extent that the jobs are comparable, is it worth the investment to have an airship just to do that particular task?

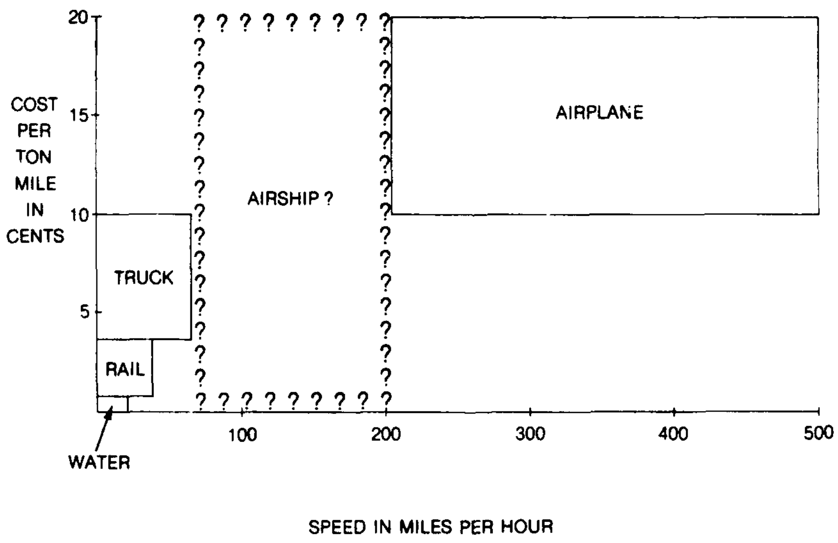


FIGURE 11

We can look at that both commercially and militarily in the same way. Figure 11 represents a range of cargo costs and speeds. The airplane runs from about 200 miles per hour to over 500 and the cost per ton mile is somewhere between 10 and 20 cents. Truck, rail, and water on the left side are slower but less expensive.

There is a natural gap that the airship can fill, but we do not know exactly where it is going to lie in terms of cost. There is no data at this time. If it is in the top of that range—for example, 100 to 200 miles per hour, 15 to 20 cents per ton mile—it is very possible it would not capture any traffic from other modes of transportation because the airplane is faster at the same cost and the truck, although slower, is less expensive, so there will be very little transfer. However, if it comes in at the bottom of that range—say, less than 1 penny a ton mile—then there is good potential for significant traffic being diverted, particularly from truck, rail and water transportation because of the greater speed.

The analysis that has been performed to date on airship and airship economics is really a function of the productivity of the airship. This is based on a number of assumptions.

When we look at the transportation modes, we do an analysis using the equations in figure 12. If you take the payload times the speed,

$$\text{MAXIMUM PAYLOAD X SPEED} = \text{HOURLY PRODUCTIVITY (H.P.)}$$

$$\text{H.P. X YEARLY UTILIZATION} = \text{AVAILABLE TON-MILES PER YEAR (ATM)}$$

$$\text{ATM X LOAD FACTOR} = \text{REVENUE TON MILES PER YEAR (RTM)}$$

$$\frac{\text{ANNUAL OPERATING COST}}{\text{RTM}} = \text{COST PER TON MILE}$$

that gives you the potential productivity of the aircraft. This hourly productivity times the hours used per year lets you know the available ton-miles per year. In other words, how much cargo could an airship carry. If you multiply this by the presumed load factor, you end up with the revenue ton miles per year—the ton miles of traffic that are sold. If you then divide the annual operating cost by these revenue ton miles, you get the cost per ton mile. Typically, for the jet airplane, 100 ton payload at 500 miles per hour gives you about 50,000 ton miles per hour. Over a 3,000 hour per year utilization, with 50 percent load factor, we end up with about 75 million revenue ton miles per year. The cost of operating a jumbo jet in this size range is about $9 million yielding a cost per ton mile of about 12 cents. Within the range of values shown in figure 11.

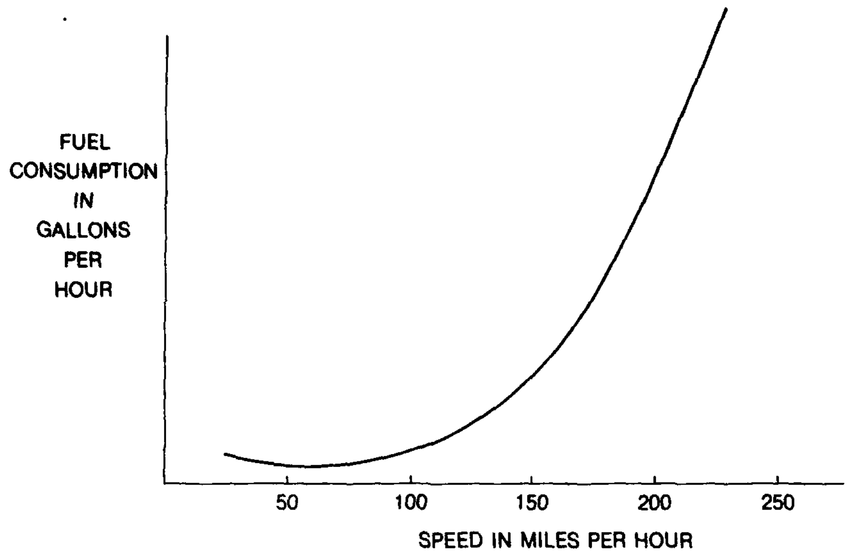


FIGURE 13

The lighter-than-aircraft can compete by carrying heavier loads or increasing its speed. Clearly it can carry large loads if we can build it large enough. However, as figure 13 shows, there is an enormous energy penalty in increasing the speed of an airship. I do not have exact numbers but studies in general indicate this type of trend: The optimum fuel economy is somewhere between 50 and 100 miles per hour and the energy consumed goes up rapidly as you approach 150 to 200 miles per hour. So we can make airships go faster but it does detract from their fuel economy, which is one of their big assets.

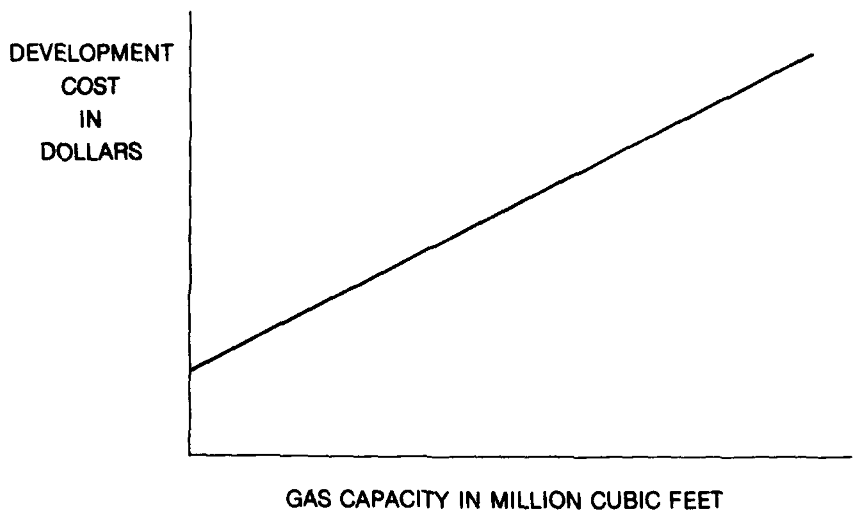


FIGURE 14

Based on the assumptions that one uses for speed, utilization, et cetera, the range of an airship's cost can go from less than 1 penny to over 20 cents per ton mile. One of the big unknowns in this is the development cost. Typically, the development cost of any new aircraft is a straight line function that is proportional to the size of the aircraft. In the aircraft industry, we use gross weights. Figure 14 shows cost in terms of gas capacity, so the basic development cost, design, tooling, all the things that are necessary before construction starts, go up directly proportionate to this.

That cost is divided by the number of units produced to get development cost per unit and, as figure 15 shows, after you get past 100 or 200 units the development cost per unit becomes very small. However, if the market will support only 10 or 20 units, the cost per unit is very expensive.

The production costs are also somewhat like those of an airplane. As figure 16 shows, the more units built, the cheaper production becomes per unit because of increased production efficiency.

Finally, all these costs can be combined to estimate the overall cost of an airship as in figure 17. Again, these numbers do not start flattening out until you produce about 100 units or more.

Figures 18 and 19 show some examples of the sensitivity to assumptions that can be made.

The wide body jet on the first line has 100 ton payload, 500 miles per hour, 3,000 hours per year utilization. These are good averages for our present system. The next several lines show the fluctuations in available ton miles per year as different assumptions are made for the airship's payload, speed and utilization. Finally, the ocean tanker by comparison has a much larger payload, much slower speed, very high utilization and comes out with very high available ton miles.

The second figure shows what happens as assumed load factors change. The assumed load factor and the assumed costs can be used

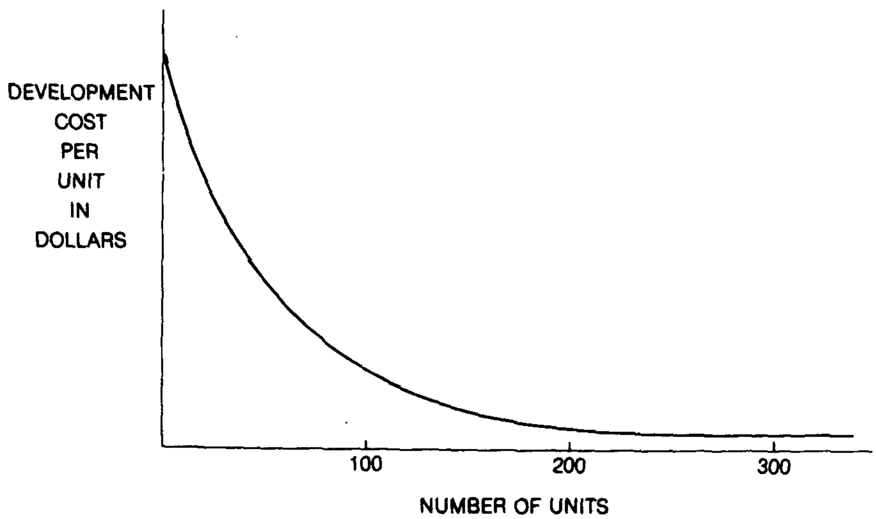


FIGURE 15

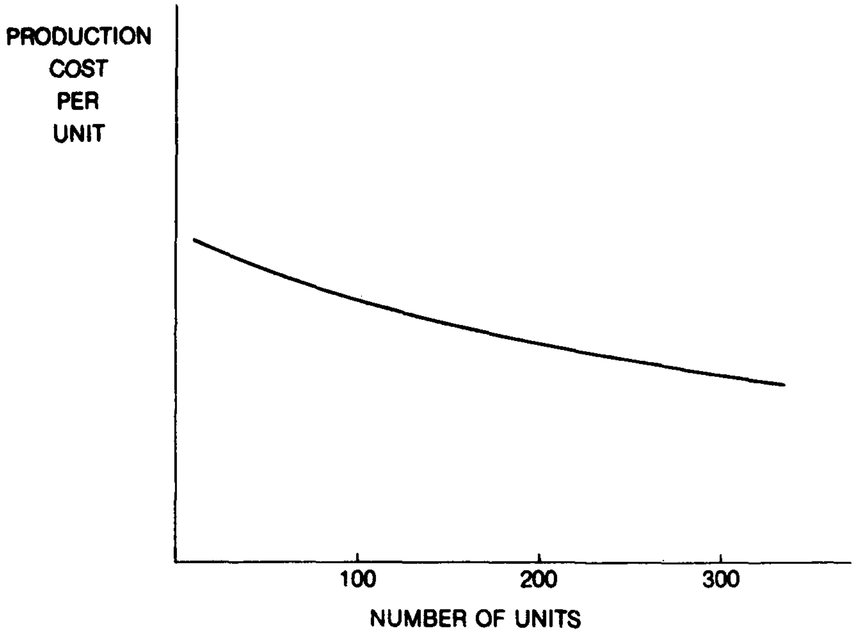


FIGURE 16

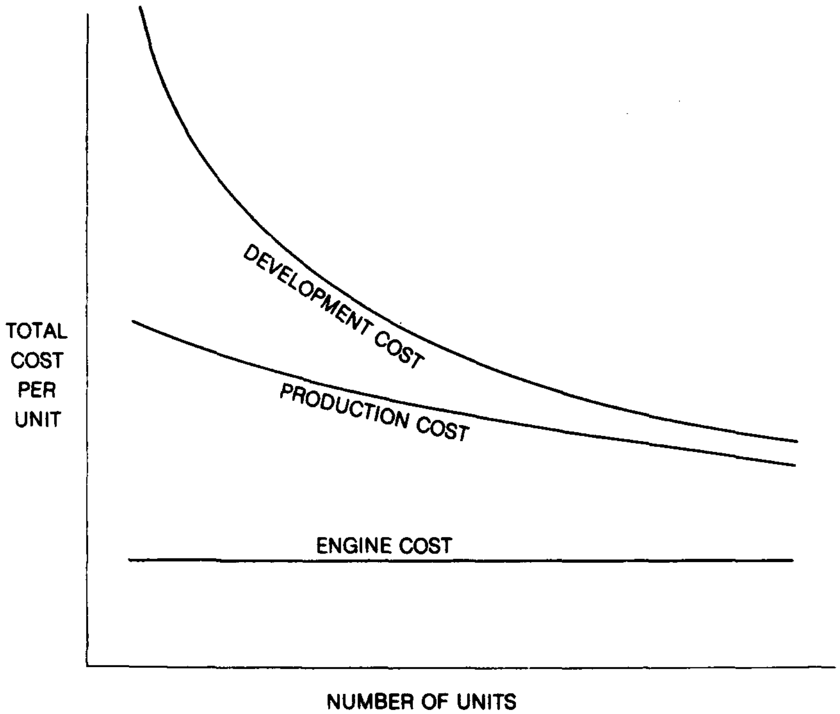


FIGURE 17

VEHICLE	PAYLOAD IN TONS	SPEED IN MILES PER HOUR	UTILIZATION IN HOURS PER YEAR	AVAILABLE TON MILES PER YEAR
WIDE BODY JET	100	500	3,000	150,000,000
AIRSHIP # 1	500	100	2,000	100,000,000
AIRSHIP # 2	1,000	200	3,000	600,000,000
AIRSHIP # 3	1,000	200	6,000	1,200,000,000
OCEAN TANKER	100,000	15	6,000	9,000,000,000

FIGURE 18

VEHICLE	AVAILABLE TON MILES PER YEAR	LOAD FACTOR	REVENUE TON MILES PER YEAR	ANNUAL COST OF OPERATION	COST PER TON MILE
WIDE BODY JET	150,000,000	50%	75,000,000	$9,000,000	12¢
AIRSHIP # 1	100,000,000	50%	50,000,000	9,000,000	18
AIRSHIP # 1	100,000,000	75%	75,000,000	9,000,000	12
AIRSHIP # 2	600,000,000	50%	300,000,000	9,000,000	3
AIRSHIP # 2	600,000,000	75%	450,000,000	9,000,000	2
AIRSHIP # 3	1,200,000,000	50%	600,000,000	9,000,000	1.5
AIRSHIP # 3	1,200,000,000	75%	900,000,000	9,000,000	1
OCEAN TANKER	9,000,000,000	50%	4,500,000,000	7,500,000	.16

FIGURE 19

to compute the cost per ton mile. As the load factor increases, the cost obviously goes down. This shows that, under a variety of assumptions, the cost per ton mile for an airship could be anywhere from 18 to 1 cent per ton mile.

There are some additional issues that we have to consider, although they are perhaps longer term. I mentioned briefly that there are institutional constraints. How would we fund the development of an airship? Secor Browne, while Chairman of the CAB, said manufacturers would not develop any airplanes in this country without some sort of Government support. And, since the development of an airship is an even greater unknown, I can't see manufacturers being willing to take the risk on their own.

How about certification? During the Graf Zeppelin's around-the-world flight, it would fly up to a mountain, below the height of that mountain and assume the updrafts were going to carry it over. I cannot see an FAA check pilot flying up to a mountain on the faith that there will be a wind current there that will carry people over the top. As for traffic control, I understand the Goodyear blimp is often mistaken for a stationary object.

Finally, regulation. Would airships come under the Civil Aeronautics Board or the Maritime Commission? Just who would regulate them? Would they be regulated at all? Who would operate them?

I have raised a lot of unknowns and some steps have been taken to answer them. Under the joint sponsorship of NASA, the Navy and the Department of Transportation, MIT is hosting a Lighter Than Air Workshop this September to address some of these issues. Many of you may have heard about it. The response has been outstanding. At this time, approximately two months before the Workshop, we have over 80 people who are definitely committed to attend. I have more than 50 abstracts submitted from Germany, France, and the United Kingdom, as well as the United States. People from developing nations are attending. The response and interest in this program have been overwhelming.

The program is structured to separate facts from unknowns and not necessarily to answer questions but to direct how to find those answers. There will be 3 days of papers presented discussing various topics: operations, economics, construction, et cetera. On the last 2 days these same people will form smaller working groups who will discuss the papers and try to design programs to answer the unknowns.

As I said, the goal is to identify programs, not to recommend that any one specific program be followed. This Workshop is a fact-finding group, a neutral group.

After these programs have been identified—what could be done, what the various costs could be—then I feel it is up to the political process to submit these findings to a group such as yours or others to see if in fact the research is worthwhile. I am sure the AIAA would take an active role in this.

So we have identified a number of questions and we are going to investigate ways to find answers. But those answers will not be evident until appropriate research programs have been completed.

I thank you very much, Senator, for allowing me to appear this morning.

Senator GOLDWATER. Thank you very much. Professor Vittek.

I have a few questions. First, what kind of money are you talking about to develop the first dirigible, the first airship?

Professor VITTEK. The estimates that I have seen are anywhere between $5 million and $500 million. I am afraid we do not have a very good handle on that problem right now.

Senator GOLDWATER. I guess that would be hard to come up with.

Professor VITTEK. As I said, it is the sensitivity to assumptions. It all has to do with the size, the capacity, the speed. So the estimates and the assumptions used are very closely tied together but there is a vast range right now.

Senator GOLDWATER. The construction would be quite different, I imagine, from the airships of the 1930's. If I remember correctly, they used semirigid, girder construction?

Professor VITTEK. Yes, but there are modern techniques that can be applied—at least people are proposing them—such as the monocoque—a solid outside covering—advanced fabrics, advanced structural materials. The Southern California Aerospace Council has done a study in this area and has indicated that present aeronautical techniques could be applied to airship construction.

Senator GOLDWATER. Do you think we have made enough advancement on construction techniques to overcome the problem of turbulence that you are going to encounter at your optimum altitudes?

Professor VITTEK. There is a tradeoff between construction to meet the optimal impact of weather and our modern techniques of avoiding weather and I think that compromise can be made. I am not sure that we could ever build a large airship that could sail into the center of a thunderstorm and come out in one piece. I am not sure that we couldn't either. But practicality would dictate a combination of avoidance plus advanced structural technique. We have the same problem with airplanes.

Senator GOLDWATER. In your prepared statement you say, and I quote, "Will the airship be closer to the airplane or the tanker cost structure?"

I think that is an interesting question. Do you have any tentative conclusions on that?

Professor VITTEK. Well, as I said, our forthcoming workshop is neutral and, as its director, I am precluded from making conclusions at this time.

However, the reason I raised that question is that the ocean tanker travels slower than an airpline. It needs a crew while it is in port. It is large. It has many of the characteristics of an airship. For example, at least in the beginning stages the airship will probably have to have a crew on board at all times. It will need several crews because we are talking 20- or 30-hour flights and it will have to carry backup crews. To that extent, it looks somewhat like an ocean liner. However, it does fly in the air.

The answer to the question I raised may be which union gets control.

Senator GOLDWATER. Do you believe the United States should build a dirigible in the near future to be used as a test vehicle?

Professor VITTEK. I cannot answer that question without prejudicing my role in leading our workshop.

Senator GOLDWATER. Well, I would like to see them do it. I will answer it for you.

Professor VITTEK. I am sorry. I don't mean to be evasive in these things but if I am going to maintain an academic neutrality and try to put forward the facts, I can't make statements like that at this time.

Senator GOLDWATER. We politicians don't have to be academic.

I think you heard the question I asked the preceding witness relative to picking up the rocket casings from the ocean. Would you like to comment on that?

Professor VITTEK. That certainly would be a very logical application of the airship. Again, does that application in itself justify the development cost? Or are there enough special applications? I don't know how many airships would be required to pick up rocket casings but I would assume a fairly small number.

Senator GOLDWATER. Do you have any views as to the role that lighter-than-air can play in antisubmarine warfare?

Professor VITTEK. It is certainly an application that is there. I gave an economic analysis relative to the transportation system. As I mentioned, the military analysis would follow the same lines. What can an airship do? What is currently being done by airplanes or ships? Do the economics justify developing the airship for those roles?

Senator GOLDWATER. Thank you very much, Professor Vittek. We did have a question from the chairman but you answered it.

Professor VITTEK. Fine. Thank you.

Senator GOLDWATER. Relative to the acceptance of the meeting in September at Monterey——

Professor VITTEK. There has been very high interest. Just yesterday I received my first reply from the Soviet Union. We invited some people from there. This person responded that he could not come but is going to submit a paper for our consideration.

Senator GOLDWATER. Thank you very much.

[The prepared statement of Professor Vittek follows:]

PREPARED STATEMENT OF JOSEPH F. VITTEK, JR., ASSISTANT PROFESSOR, AERONAUTICS AND ASTRONAUTICS, ASSOCIATE DIRECTOR, FLIGHT TRANSPORTATION LABORATORY, MASSACHUSETTS INSTITUTE OF TECHNOLOGY: CHAIRMAN, LIGHTER-THAN-AIR SUBCOMMITTEE, AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

THE POTENTIAL AND PROBLEMS OF LIGHTER-THAN-AIR TRANSPORTATION

Mr. Chairman and members of the Committee, as neither an advocate nor an enemy of lighter-than-air transportation, I am interested in separating fact from speculation. In the past few years there has been much discussion both here and abroad of the ability of lighter-than-air vehicles to meet future transportation needs. Many of the proposed uses and missions seem promising. However, lighter-than-air is not without its problems. Although modern technology may be able to overcome these problems, the ultimate issue is the economic feasibility of lighter-than-air when the costs of modern technology are included in the price of the service and the demand for the service at that price is determined.

THE POTENTIAL OF LTA

The airship has certain advantages over alternate modes of transportation. Like a ship or barge, it can move large bulk and weight shipments over long distances. Unlike a ship or a barge, it need not follow established waterways. Nor does it require terminal facilities. The airship offers these same advantages over railroads and has considerably greater capacity than trucks. Even though a high-cargo-capacity airplane could be developed, it would require large runways at both ends of its trip. Thus, the airplane lacks the airship's flexibility.

Because of the inherent advantages, several LTA missions can be identified. One often mentioned is the use of LTA to improve trade of developing nations allowing the movement of bulk commodities and crops out of otherwise inaccessible areas. Another mission is the transportation of bulky machinery such as nuclear power generation equipment too large to move over normal highways or rail right-of-ways. Its large capacity, coupled with the ability to hover, makes LTA a candidate for construction tasks—the proverbial "sky hook." These same characteristics could be used for disaster relief when normal transport facilities are damaged.

Other uses such as spraying crops, geological survey, archeological expeditions, military reconnaissance and anti-submarine missions are also discussed.

For passenger travel, the airship could revive an era of elegance no longer available. Although some feel the airship might compete for city-center to city-center short haul traffic, its true role would probably be the cruise liner of the air.

All these uses, coupled with the airship's potential for low pollution, low noise and energy efficient flight, have rekindled public interest and imagination in these "ships of the sky."

LTA PROBLEM AREAS

The promise of LTA is not without its problems. Most are directly related to the large size of a lighter-than-air craft.

Ground Operations

Although LTA vehicles may hover while transferring cargo, etc., they still have a requirement for home bases for maintenance, repairs and refurbishing. The least this will require is an open area and a mooring mast or other tethering device. For some of the larger airships proposed, the clear area needed for maneuvering, particularly in response to wind shifts, could be quite extensive. To handle more than one airship at a time, the land area needed approaches that of a large scale airport. The cost of these facilities could also be high if large airship sheds or docks are required.

Ground handling techniques present a second problem. Although by the mid-1960's the hundreds of ground handlers required in earlier days had been reduced through mobile masts and winches, numerous ground personnel were still needed.

Even today, about 10 ground handlers are needed to land a Goodyear blimp, a relatively small lighter-than-air craft. In fact, it is so dependent on its ground handlers that it must often circle a destination waiting for its ground crew, who travel by highway, to catch up and erect the mooring mast.

An additional operational problem occurs when payload is taken on board or discharged. Under normal operating conditions, an airship has approximately neutral buoyancy. That is, it will neither rise nor descend unless additional forces are applied. The upward lift is balanced by the downward pull of gravity.

When the airship is loaded or unloaded, its weight changes, destroying the equilibrium condition. Normally, ballast is also loaded or unloaded to retain the neutral state (although reducing the amount of lifting gas would have the same effect). This means that if the airship is delivering or picking up cargo at some undeveloped site, there must also be provisions for ballast and transferring that ballast. Alternatively, some on-board system is needed to change the gas volume. But such a system may be too heavy to justify.

Air Operations

The replacement of hydrogen with non-flammable helium as the lifting gas has shifted the major danger of an airship catastrophe from fire to structural

failure in violent weather. This was clearly the fate of the Shenandoah and the Macon, and perhaps the Akron.

Undoubtedly, better structures can be designed today than 40 years ago. And modern materials can provide increased strength with decreased weight. But as the size of proposed airships increases so do the bending and twisting forces that may arise during operations. Although theoretically the lift capacity of an airship grows as the cube of its size while weight increases only as the square, it is not clear whether the structures required to meet the dynamic forces encountered by large airships will still follow the theoretical laws or instead impose weight penalties due to safety considerations that will decrease payloads.

Another problem associated with the structure of an airship is its maintainability. There are many examples in airship history of minor ground handling errors damaging the skin or interior bracing leading to substantial down-time for repairs. Such questions of damage susceptibility, structural integrity and maintainability raise doubts as to the reliability of airships and their ability to reach the degree of utilization needed for commercial success.

Airships also face an operational constraint on their altitude. As an airship rises, the external air pressure decreases. Therefore, the gas inside the airship expands. When the internal gas expands to the limits of the gas cell, the airship can go no higher without bursting or somehow removing gas from the cell. This altitude is called the "pressure altitude." To raise the pressure altitude, the airship can start its flight with less gas. However, this decreases payload. The compromise solution developed by airship operators was to cruise at about 1,500 to 2,000 feet with a pressure altitude of about 6,000 feet. The resulting circuitous routings in mountainous areas increased both time and fuel consumption. The economic impact of such procedures at today's labor and fuel prices is unknown.

TECHNICAL SOLUTIONS

Technology available today or in the foreseeable future can alleviate many of these problems. Perhaps the most useful technological innovations would be the application of modern sensors and variable thrust and direction engines to both stabilize position and perform precise maneuvers. As in the Apollo spacecraft, inertial sensors that detect directional and rotational forces can be coupled through a computer to active control systems. This would allow rapid detection of undesired motion and the application of corrective forces to counter the motion before it becomes too severe. This type of system would improve ground handling and air operations.

Television cameras could be used to monitor the parts of the airship not directly observable. They would also provide the crew with extra eyes during precise maneuvers such as docking. Radar altimeters would provide better knowledge of altitude. Better radio and navigation equipment would provide considerably more information than an old and experienced zeppelin captain would have ever thought possible.

Modern weather prediction techniques and frequent forecast updates would allow the safe circumvention of storms, as would airborne weather radars.

Computerized structural design techniques would permit more accurate analyses of the stresses and strains an airship would have to endure. This, coupled with today's knowledge of storm intensities and shear forces, would lead to structures designed to withstand the worst weather possible. And the application of titanium and composite fiber materials would minimize the weight of these structures. New synthetics are available to make stronger-while-lighter-weight coverings.

The use of on-board gas compression systems would alleviate some of the problems of pressure height and ballasting mentioned, although the weight of current systems would have to be reduced. Likewise, nuclear propulsion could be used to extend range and eliminate the need to use water recovery or other ballasting techniques to compensate for the loss of weight as fuel is consumed.

In short, the technology is available to address many of the problems of lighter-than-air already discussed. The basic question remains whether the demand for lighter-than-air services is sufficient to offset the costs of this technology as reflected in the price that would have to be charged for the service.

ECONOMIC ISSUES

For any new method of transportation to gain acceptance, it must offer an improvement over existing systems, in terms of performance or cost or both. Therefore, to be a commercial success, lighter-than-air must capture traffic from an existing mode of transportation by offering a better service or generate new traffic by offering services not currently available.

It is extremely difficult to predict what new markets or types of traffic might be developed if airships did exist. Some come to mind, such as the transport of bulky power generation equipment to remote sites, but the demand for such applications is limited. In any case, it is doubtful whether the management of a potential airship manufacturer would commit funds for development based on such speculation alone. Therefore, the remainder of this discussion will concentrate on the share of traffic airships might capture from traditional modes.

LTA's ability to lure traffic from other modes will depend on the types of markets it can serve. At the present time, most time-sensitive shipments travel by truck for short distances and air for long distances. But speed is expensive. Truck costs average around 7 cents per ton-mile. Air may run as high as 20 cents per ton-mile (although container rates for belly cargo in wide-bodied aircraft are in the range of 8 to 10 cents per ton-mile, approaching truck rates). Rail traffic is slow and more suited to bulk commodities, with costs in the range of 2 to 3 cents per ton-mile. At the bottom of the spectrum is ship or barge traffic, slower still, but with costs approaching 1 cent per ton-mile or less.

In terms of speed, the airship is superior to surface modes, but inferior to the airplane. In terms of capacity, the airship is superior to the truck and airplane, but inferior to large trains, barge tows or ocean transports.

If the costs of airship freight were the same as for aircraft, the airship would not capture any traffic from another mode. At the same cost, traffic could move at the higher speed of air since fewer people would want less service for the same price.

If the costs of airship freight were similar to those of truck, the airship would capture that portion of the current air freight market that is semi-time-sensitive—traffic that must move faster than truck but does not have to travel at jet speeds. Currently, it moves by air because there is no alternative. An airship with costs less than air and speed greater than truck could capture this market.

The airship with costs similar to truck would also capture some traffic now moving by truck, but not all. Trucks, because of their door-to-door capability would still offer an overall time advantage in many markets. Also, smaller shipments that comprise less than a truckload would probably still move by truck to avoid the rehandling required to load them on an airship. Large shipments that currently move in multi-truckload lots (such as agricultural crops) would be the prime candidate for using airships instead of trucks.

If the cost of airship freight were comparable to bulk carriers such as train, barge or ocean transport, the airship would capture a large share of the bulk market. However, much traffic would still move by traditional modes—some because established collection and distribution patterns are based on current line-haul methods and would cost too much to change, some because the traditional mode can carry more in one shipment than several airships (e.g. 100,000 ton tankers) saving transfer and handling costs.

The discussion so far has been based on United States domestic rates. A different picture emerges in developing nations. Unlike the United States, most underdeveloped areas do not have an extensive transportation infrastructure—i.e. existing highways, railroad track, canals, airports and port facilities. If the costs of these facilities are included in the calculation, the airship's relative economies would improve greatly since it does not need an expensive infrastructure.

Similar analysis can be performed for military applications by comparing the airships to ships, helicopters or whatever craft is currently needed for a particular mission.

In any case, the extent to which airships will capture traffic carried by present modes of transportation will primarily depend on the costs of airship service.

What these costs will actually be is the major unanswered question of lighter-than-air. The methods for calculating those costs are straightforward. However, the results are extremely sensitive to the assumptions used and assumptions must be made because actual data is virtually nonexistent.

To determine cost per unit of output, say the ton-mile, total output over some time period is computed. This is then divided into the total cost over that same period. As a first step, one computes the productivity of the vehicle. This is the product of the vehicle's payload capacity and its speed. Thus, by multiplying the lift capacity in tons (available tons) by the speed in miles per hour, one gets the productivity in available ton-miles per hour.

$$\text{available tons} \times \frac{\text{miles}}{\text{hour}} = \frac{\text{available ton-miles}}{\text{hour}}$$

Multiplying this result by the hours of utilization expected in one year yields the potential traffic-carrying capacity of the vehicle in one year.

$$\frac{\text{available ton-miles}}{\text{hour}} \times \frac{\text{hours}}{\text{year}} = \frac{\text{available ton-miles}}{\text{year}}$$

But vehicles are not always full. Therefore, this available capacity must be multiplied by the load factor to get the revenue ton-miles per year.

$$\frac{\text{available ton-miles}}{\text{year}} \times \text{load factor} = \frac{\text{revenue ton-miles}}{\text{year}}$$

If the total costs for the year are now divided by the revenue ton-miles, the result is the cost per revenue ton-mile or the cost per ton-mile carried for profit.

$$\frac{\text{cost/year}}{\text{revenue ton-miles/year}} = \frac{\text{cost}}{\text{revenue ton-mile}}$$

As an example, a wide-bodied jet freighter can carry about 100 tons (200,000 pounds) at about 500 miles per hour. Thus its productivity is

$$100 \text{ tons} \times \frac{500 \text{ miles}}{\text{hour}} = \frac{50{,}000 \text{ ton-miles}}{\text{hour}}$$

At a typical utilization of 3,000 hours per year, the total yearly capacity would be 150,000,000 available ton-miles. A 50 per cent load factor would yield 75,000,000 revenue ton-miles per year. The annual direct operating cost of such an aircraft would be about 6,000,000 dollars. In an all-freight airline, the indirect costs are typically about 50 per cent of the direct. Therefore, total annual costs would be about 9,000,000 dollars, yielding a cost per revenue ton-mile of about 12 cents.

Similar calculations can be made for a lighter-than-air vehicle. But because of a lack of valid data, many assumptions must be made. For example, several engineering studies indicate that a 200 mile-per-hour airship with a 1,000 ton payload is technically possible. (There are also studies that challenge this position.) If the utilization is 3,000 hours per year as for an airplane and a 50 per cent load factor is assumed, the yearly capacity would be 800,000,000 revenue ton-miles—four times that of the wide-bodied jet. If the utilization were 6,000 hours, in the range of an ocean tanker, the yearly capacity would jump to 600,000,000 revenue ton-miles—eight times that of a wide-bodied jet.

If, however, we make different assumptions, the results change drastically. If the most economical speed for an airship is 100 miles per hour (which is above the cruising speed of the Graf Zeppelin and other early rigids), the payload is 500 tons instead of 1,000 and the utilization is 2,000 hours, the annual capacity at a 50 per cent load factor drops to 50,000,000 revenue ton-miles—two-thirds that of a wide-bodied jet. If the yearly operating costs were the same as a wide-body under each set of assumptions, the cost per ton-mile would vary inversely as the annual revenue ton-miles carried—or from less than 2 cents per ton-mile under the most favorable assumption to 20 cents per ton-mile under the least favorable. Yet all these assumptions are quite reasonable.

On the cost side, the largest unknowns are the cost of the airship itself and its useful life. The cost of the airship is determined by four major

factors: the total development cost, the number of units produced (needed to compute the development cost per unit), the construction cost per unit and the cost of the engines. Reasonable estimates of the latter can be obtained since a first generation airship would no doubt use available engines. All the other variables are unknown. Estimates of development costs run from 50 to 500 million dollars. The number of airships needed has been estimated between 10 and 100. Construction cost estimates also vary considerably. Thus, the price per airship could vary between perhaps 15 and 150 million dollars.

Having purchased an airship, the operator would depreciate it over some useful life. The annual depreciation cost is part of the annual operating cost used to determine cost per ton-mile. Assuming a 25,000,000 dollar airship with a 10 year life, the annual depreciation cost would be 2,500,000 dollars. In an airline operation, depreciation is typically 10 per cent of the total operating cost. Based on 2,500,000 dollars depreciation, the annual total airship operating cost would be 25,000,000 dollars. In an ocean tanker operation, the depreciation represents about 50 per cent of the direct cost. Under this assumption, the annual direct cost would be 5,000,000 dollars. Indirect cost is assumed to add another 50 per cent to the direct cost for a total annual cost of 7,500,000 dollars. Will the airship be closer to the airplane or the tanker cost structure?

These exercises point out how sensitive study results are to the assumptions used. An error of a factor of two or three can substantially alter the results in terms of cost per ton-mile. And differences of but a few cents per ton-mile may prevent airships from capturing traffic from other modes and spell financial disaster for operators.

INSTITUTIONAL CONSTRAINTS

A final set of problems is that imposed by government regulation, union contracts and the like. Perhaps the most important is how will airship development funds be raised? Secor Browne, before he left the Civil Aeronautics Board, said that the United States aircraft industry could no longer afford to develop new aircraft and requested legislation to alleviate this problem. If it is true that the aerospace industry cannot afford to develop new heavier-than-air vehicles, a field in which they have great experience and are world leaders, can it be expected to underwrite the development of airships—with all their inherent unknowns?

How will airships be certified? The Federal Aviation Administration has been attempting to develop standards for STOL aircraft for several years, although the differences between STOL and conventional aircraft are not that dramatic. How long will it take to develop standards for commercial airships? How will airships be tested? What safety standards will apply?

How will airships be handled by the air traffic control system? At the least, because of their relatively low speeds and altitude restrictions, special procedures of some type will be needed.

Will airships be operated by airlines? By shipping companies? Will certificates of public convenience and necessity be required? Will the aviation or the maritime unions have jurisdiction? Will the Civil Aeronautics Board or the Federal Maritime Commission have jurisdiction? What of our international bilateral agreements? Will they apply or will new negotiations be needed?

Although these issues are currently overshadowed by the technical and economic questions, they must at least be considered.

HOW CAN THE UNKNOWNS BE ANSWERED?

Thus far, possible uses and associated problems of airships have been discussed. How are the conflicts and the unknowns to be resolved? As a first step, the Office of the Secretary of Transportation, the Federal Aviation Administration, the Navy and the National Aeronautics and Space Administration have contracted with the Massachusetts Institute of Technology's Flight Transportation Laboratory to conduct a week-long workshop on lighter-than-air in September of this year. This is in addition to other studies already underway or planned by these agencies.

Workshops have been used for many years to bring together a group of people knowledgeable on a particular subject for an intensive period of discussion and interchange of ideas. As many representatives of different perspectives and viewpoints on LTA as can practically be expressed will be invited to participate at all levels of the program. Some participants will come for only one session, some will attend the entire program.

The goal of the lighter-than-air workshop is to establish what facts are known about LTA's potential, what are the unknowns and, in turn, to identify programs (and their cost) that could answer some of the unknowns. As a fact-finding body, the workshop will not adopt an advocacy position for or against potential programs or for or against lighter-than-air in general.

After three days of papers and presentations on various lighter-than-air topics such as missions, construction techniques and operational economics, workshop participants will spend two days discussing the presentations, identifying areas that need further investigation and proposing programs that could be undertaken to answer the unknowns.

It is hoped that the options developed will serve as a starting point for further research if the costs seem justified by the airship's potential. Although the workshop is not designed to answer many of the questions raised, it may point the way to answering these questions and, indeed, to separating fact from speculation once and for all.

Senator GOLDWATER. I have some material on lighter-than-air aircraft that I would like included in the record at this point.

[The material referred to above follows:]

[Reprinted from the Congressional Record, Oct. 30, 1973]

WHY NOT BLIMPS?

Mr. GOLDWATER. Mr. President, NASA is currently studying the various ways to move the Space Shuttle from point to point within the Earth's atmosphere. The need arises because NASA will have to move the Space Shuttle from the factory to either the Kennedy Space Center at Cape Canaveral or Vandenberg Air Force Base in California. Moreover, the Space Shuttles may have to be moved from one launch site to another owing to mission requirements.

I am informed that NASA is considering various ways of moving the Shuttle in level flight, among these are: fitting air breathing engines in a strap-on mode, modifying a C-5A as a piggy back carrier, joining together two 747s, towing the Shuttle behind a transport aircraft.

All have serious drawbacks.

Why not blimps?

I have written to Dr. James C. Fletcher, the Administrator of NASA suggesting the possibility of blimps or dirigibles. They have the following attractive features:

First. Low power requirements.

Second. Low noise levels.

Third. High inherent stability.

Fourth. No runways needed.

Fifth. Great ability to hover.

America has a plentiful supply of helium to provide buoyancy—buoyancy without the threat of fire.

From the foregoing it seems clear that blimps or dirigibles would be socially acceptable. They would not consume great quantities of fuel. They would pollute less. They would not add appreciably to existing noise levels. Finally, blimps are friendly.

The only real technical problem that I know of involves the takeoff and landing. Years ago large crews were used to assist takeoffs and landings by handling tethers. Inevitably, there were injuries. And, the high cost of large standby crews might be prohibitive today. I believe this problem can be solved by using modern technology.

Mr. President, I ask unanimous consent that the text of my letter to Dr. James C. Fletcher be included at this point in the Record.

There being no objection, the letter was ordered to be printed in the Record, as follows:

"U.S. SENATE,
COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES,
Washington, D.C., October 29, 1973.

"Dr. JAMES C. FLETCHER,
Administrator, National Aeronautics and Space Administration,
Washington, D.C.

"DEAR DR. FLETCHER: As you know, NASA is considering various ways of moving the Space Shuttle from point to point within the USA. I would like to suggest that you consider the possibility of using either blimps or dirigibles.

"If blimps and dirigibles looked attractive from economic and engineering standpoints, it would provide NASA with a multipurpose means of transportation. For example, the solid rockets and the tanks for the Shuttle could be moved by them.

"As far as I can tell, it has been a long time since the U.S. Government has studied the economics and engineering of blimps and dirigibles. If such a study were made in conjunction with the Space Shuttle, I would like to suggest that NASA simultaneously study blimps and dirigibles as a method of commercial transportation. One purpose of such a study might be to answer this question: What kinds of cargoes, if any, could they haul economically?

"I am sure you can appreciate the favorable public reaction that would occur if NASA was able to provide technology for moving food from the farm to the marketplace in a cheaper, faster way.

"With warmest personal regards, I am

"Sincerely yours,

"BARRY GOLDWATER,
Ranking Minority Member."

Mr. GOLDWATER. Mr. President, in the October, 1973 edition of the Astronautics and Aeronautics, there is a very fine article entitled, "The Many Uses of the Dirigible." It authors are Jack R. Hunt, Ben B. Levitt, Francis Morse, Kurt R. Stehling, and J. Gordon Vaeth. They point out that many people have an adverse reaction to dirigibles, because of bad memories of the *Hindenburg* which blew up at Lakehurst, N.J., in 1937. The *Hindenburg* used hydrogen for buoyancy and thus was highly susceptible to explosion. German zeppelins had to use highly volatile hydrogen as a result of a U.S. embargo on helium.

However, it is a fact that during the years 1936–37, German zeppelins made over 200 transatlantic flights on schedule or nearly so. On one occasion during a flight to Rio de Janeiro, a zeppelin was unable to land as there was a revolution in progress. The airship simply maintained station over the Atlantic until the airport resumed operations.

The authors see many uses for the dirigible. The one that impresses me the most is that of a cargo carrier.

I know many Senators have received letters about the boxcar shortage. Many communities throughout the land have been short of transportation.

I believe it is time for NASA to take a new look at blimps and dirigibles—a new look at the engineering and economical problems involved. I don't believe NASA should go full bore into development. I do believe NASA should provide study money to take a further look at blimps and dirigibles from the vantage point of 1973 economics and technology.

Any transportation system promising low noise and low fuel consumption deserves some consideration today.

Mr. President, I ask unanimous consent to have the article entitled "The Many Uses of the Dirigible" printed in the Record.

There being no objection, the article was ordered to be printed in the Record, as follows:

"THE MANY USES OF THE DIRIGIBLE

"(Modern technology combined with still unrivalled payload, internal volume, range, and endurance will equip the airships of the future to do the jobs no other vehicle can.)

"The revival of large airships could provide the United States with a dramatically new and different technological challenge. (See, 'Dirigibles:

Aerospace Opportunities for the '70s and '80s,' in the November *A/A*.) But engineering challenge alone will not attract enough support. Dirigibles must be needed. They must be able to do things no other aircraft can do as well or do at all. We will detail some of these singular talents in this article.

"But remember, in evaluating the dirigible's renewed usefulness think in terms of future airship design and performance. Thirty-six years have passed since the *Hindenburg's* hydrogen caught fire at Lakehurst. Yet most persons visualize tomorrow's helium-filled dirigibles as more *Hindenburg's*. This is like trying to predict the usefulness of a future airplane by what the Ford Trimotor or DC-3 could do.

"Remember also that different application will require different designs and configurations. Size will vary according to purpose. Some applications will require nuclear propulsion; others will be better served by more conventional power. And, recalling that the Zeppelins of WW I carried loads to 10,000 ft. we must expect, too, a variety of cruising altitudes and speeds.

"Also keep in mind that airships are *not* unduly weather-sensitive. Ground handling in severe weather admittedly takes great care, but once airborne airships take on quite a different nature. For this reason future uses of the dirigible anticipate their remaining aloft as much as possible, and loading or unloading passengers, freight, supplies, and crew by hoist, hook-on planes, or perhaps helicopters.

"The German Zeppelin operators of the 1920s and '30s, pioneers in pressure pattern navigation that they were, actually chased after storms to hitch a ride on the wind circulation around them. In this way the *Hindenburg* once reached a ground speed of 188 mph. After [illegible]e years of flying the North and South Atlantic, Zeppelin captains learned [illegible] respect penetrating fronts rather than fear it. Trim the ship, place it in static equilibrium, and at low altitude enter the light spots was what they routinely did—and without benefit of radar. Localized thunderstorms they circumnavigated. More than a half million hours safely flown by the Navy blimps in WW II reinforced the Zeppelin men's conclusion.

"Not even icing presents the hazard supposed. Protracted flights in rime icing have shown that an airship picks up a static load equal to about 5% of its gross weight after which no more builds up. Glaze icing poses an insignificant hazard owing to its random distribution over the surface of the ship and the short time during which glaze icing conditions persist. Snow does accumulate but not in dangerous amounts for airspeeds above 40 kt.

"This icing information came out of all-weather stationkeeping carried out in January 1957. While the most severe winter weather in 75 years hit New England, Navy blimps from a squadron at South Weymouth, Mass., and from another at Lakehurst, N.J., manned a point 200 mi east of New York City, keeping at least one airship on station at all times for 10 consecutive days. Meanwhile, weather grounded commercial carriers for three of these days at all major Northeast airports. After this performance airships hardly deserved dismissal as 'fair weather aircraft.'

"But this is history. The technology used in future airships—the nature of their skin, the ducting of heat, the use of embedded electrical elements, the carrying of balast that doubles as deicer fluid—would overcome any remaining icing handicaps as surely as modern techniques have done so for airplanes.

"Designing, building, and operating large structural airships makes perfectly sound engineering sense. Whether Zeppelins, metal-clads, or some other type, however, their engineering must permit a suitable magnitude of deflection throughout their structure, something that was not always done in the past. Given this structural flexibility and given the level of technology that made possible the Boeing 747 and the Saturn V, nothing prevents building airships as airworthy as any other man-made thing that flies.

"The dirigible's appeal for the future lies in certain characteristics possessed either not at all or to only a limited or lesser extent by other aircraft. Inherently it makes an environmentally clean vehicle which could appreciably reduce pollution caused by aircraft operations. It combines very large payload with extreme range and a flight endurance measurable in days, weeks, or with nuclear power, months. Substantial shipping holds could carry bulky cargo. It could transport outsized items, such as preassembled structures, slung beneath the hull and accurately lower them into place while hovering overhead. Sightseers, arms-control observers, land or sea bed treaty inspectors,

mappers, geologists, agriculturalists, oceanographers, biologists, coastline surveyors, doctors and nurses, rescue workers, salvagers, archeologists, and others could travel abroad by the hundreds and with room to work and live comfortably. For mounting sensitive equipment the structure of a large dirigible would prove convenient as would the airship's standing as perhaps the most stable and vibration-free propelled airborne platform man can build.

"The usefulness of a dirigible is a function of its volume. The *Hindenburg's* 7-million cu. ft. approached an efficient size for its purpose, its day, and its hydrogen inflation. Lighter materials and improved structures would reduce dead weight and improve performance in the future. Even so, tomorrow's missions would require larger sizes—nine-, twelve-, perhaps twenty-two-million cu. ft.

"Projections set the payload of a 22-million cu. ft. conventionally propelled airship of conservative design at 615,000 lb for a range of 2950 mi, and 326,000 lb for 6500 mi. With nuclear power the payload remains 655,000 lb regardless of range. This is impressive carrying power by any standards. Corresponding payloads for the C-5A—considered by some the largest cargo airplane practical—reportedly weigh 265,000 lb and 80,000 lb, respectively, nowhere near the airship's.

"With performance like this and that graphed at right, dirigibles could well become *merchant ships of the air,* carrying low-density and large-dimension cargoes that jet freighters find economically unattractive or practicably impossible to handle. Airships could transport these shipments nonstop at 100 or more mph (depending on design and powerplants) across oceans and then deep into continental interiors. At destination, they could unload without landing, using propeller thrust-vector control and other techniques to help maintain position and compensate for changes in weight. If the cargo happens to require a landing, they would need only a flat clearing and simple stick mast. They would need no costly port terminals or thousands of feet of heavy-duty runways.

"This ability to bring large (in size and weight) cargoes into and out of areas without landing facilities would make the airship a logical candidate for introducing trade into the underdeveloped and inaccessible regions of Africa, South America, and Asia.

"As *aerial cruise ships* dirigibles also have much to offer. The *Hindenburg* was considered the quietest form of transportation then available. The noise level in its passenger quarters ranged between 40 and 61 dB. It flew so smoothly that tall vases holding cut flowers safely stood on its tables. Scarcely a ripple disturbed the surface of water or wine in goblets. Absent were the often abrupt motions of heavier-than-air flight. No one got airsick.

"Passengers had accommodations like those on a luxury steamer. They particularly liked the large outward-slanting draft-free windows along the promenade decks. These windows usually remained open and through them passengers could look directly out at the scenery beneath. Because the ship cruised at about a thousand feet, it offered spectacular sightseeing. Those who paid their $400 to fly the Atlantic this way sat or stood for hours before the windows. They described the experience of traveling on the *Hindenburg* by saying, 'You fly on an airplane but you voyage on an airship.'

"An even more enjoyable flight would await those who cruise on tomorrow's dirigibles. The anticipation of gliding slowly over and around the islands of the Caribbean and of exploring from comfortable quarters in the air the historic and picturesque coastlines of the Mediterranean would almost certainly attract vacationers in large numbers. Imagine the thrill of hovering low over the canals of Venice or the ruins of ancient civilizations and seeing and photographing them unhurriedly in detailed plain view. Consider the appeal of following a river like the Amazon, poking around the Arctic ice pack in the summer, or circling the globe, all while aboard an airborne resort hotel. For land excursions passengers could be ferried to the ground and back by airplane. Or the airship might ride to a sea anchor offshore and lower its guests to the surface where waiting hydrofoils would take them into port.

"Cruise activity, a major part of the maritime scene, has fallen captive almost entirely to foreign-flag ships. A new type cruise vessel, something entirely different, to attract U.S. and other tourists would help reduce the substantial dollar outflow resulting from recreation travel.

"The leisure use of the dirigible contrasts sharply with its value for *giving assistance and saving lives following natural disasters.* Earthquakes, typhoons, storm surges, floods, landslides, and other such calamities continually remind us of our inadequate preparations for dealing with them. Each invariably touches off a frantic international effort to provide assistance. How well that effort succeeds depends on where the tragedy strikes and how accessible by air. If airports have been crumpled, submerged, washed away, or if they simply do not exist nearby, help is tremendously hindered. Even when runways remain open, chaos may prevent distributing items airlifted. Such conditions reportedly existed after last year's Managua earthquake.

"A dirigible could carry for thousands of miles hundreds of thousands of pounds of supplies and deliver them directly into the hands of survivors and evacuees without depending upon usable runways or airports. It could take food, water, water purifiers, medicines, tents, sleeping bags, generators, communications equipment, vehicles, pumps, demolition gear, and even bulldozers. In hovering flight it could intensely illuminate an area at night. Cables could carry emergency power to the ground. Using the airship as an aerial vantage point experts in rescue, firefighting, demolition, and the restoration of essential services could oversee and direct activities. To play its role in disaster relief, such a ship must be specially configured to contain hospital facilities, for example. Provided the payload, speed, range, and altitude capability to rapidly reach almost any inhabited place on Earth, it will almost certainly comprise the most technologically advanced airship flying.

"When not on disaster service, it could improve international well-being many other ways. Going into remote regions, it could seed plants from the air and dust crops. In areas of Africa afflicted by locusts, it could reach and spray the breeding area. It could accurately chart land use and help evaluate its management, stock inland waters with fish and nutrients, take fishery surveys, and wildlife censuses and track the migration of whales. An airship could spray or literally mop up large oil spills at sea operating above and free of the mess, criss-crossing the spot to lay down chemicals or tow booms or other devices to clean the surface.

"This vehicle of global goodwill, this flying symbol of American or international humanitarianism could take well-equipped teams of geologists, geodesists, biologists, and other scientists, also engineers, to areas of interest and deposit them for *in situ* sampling, exploration, excavation, and construction. Archeological expeditions could reach their destinations this way. All the while, however, the ship would remain equipped and ready for its prime mission. With the first word of a natural calamity, it would set course immediately for the scene, picking up the needed medical and other specialists on the way by airplane hook-on.

"A similar but less spectacular role can also be visualized for airships as airborne versions of the medical ship *Hope*. Equipped as flying clinics and training centers and routinely bringing health care and instruction to the hinterlands, they could help people and communities beyond the direct reach of the famous humanitarian vessel.

"In its survey operations for the public good, the dirigible would demonstrate its special talents for *remote sensing.* Certain frequencies now carry atmospheric, oceanographic, and Earth-resources radiometric observations, because they are the best permitted by the antenna-carrying limitations of today's air and space craft. The airship's size, stability, and low vibration would permit carrying environmental and geophysical sensing antennas that would open up a new world of frequencies to use. Sensitivity, gain, and resolution should improve remarkably.

"Gravitometers and magnetometers, trailed if necessary to remove them from the effects of the ship, could be carried as could very high-resolution cameras and laser profilometers. Remote-sensor technologists would appreciate the airship's ability to carry on-board processing facilities. They could identify questionable results while the ship is still in or near the observing area and repeat runs using the same or different instruments, frequencies, or spectral intervals.

"Current technology has not revised the WW I verdict that airships make poor combat aircraft. It would permit improving their ability to survive if attacked. Damage control would become feasible in a large rigid or structural airship, since repair parties could reach its frame, engines, and gas

cells in flight. More important, it could carry self-defense aids, consisting of early warning and fire-control radars, anti-air and antimissile missiles, also other countermeasures suitable to the threat. Even so, prudent operation must keep the ship out of situations for which it is not intended. The vulnerability considerations of an airship do not differ from those of any other military vehicle, be it troop transport or aircraft carrier. Each must operate in the tactical environment for which its designers intended it to have an acceptable level of survivability.

"The airship's ability to deliver large quantities of men and supplies into remote areas with little or no ground support gives it an important military role.

"But it has a much more significant one as a *platform for ocean surveillance*—surface, air, and underwater—for sea control. Using the immensity of its sides, an airship could fly a phased-array radar with the power and performance to mount an intensive watch over large areas of the ocean surface. Other sensors, infrared and over-the-horizon radar, might also find uses.

"If the dirigible could classify detected targets, it could fire air-to-surface weapons at unfriendly ones. If it could not, it might launch its own aircraft to classify, and, if necessary, to attack them. It will want to use its planes too when keeping silent its own high-powered surveillance radar to avoid detection.

"It could carry out air surveillance in a like manner but with an additional consideration. If friendly forces occupy the area of interest, the enemy must not be allowed to conduct aid reconnaissance there. Denying the enemy targeting intelligence will significantly improve the survival chances of friends. The effectiveness of standoff surface-to-surface missiles decreases as uncertainty increases about the location, composition, and disposition of potential targets. Some cruise missile submarines reportedly receive their targeting data from reconnaissance aircraft. Deprived of such information they must stay close to acoustic detection range where they have much more difficulty locating and classifying targets.

"Air surveillance should permit the airship to detect cruise missiles in flight, thus giving warning of attack and providing it the opportunity to launch counter missiles or to vector intercepting aircraft. As for submarine-launched ballistic missiles, particularly those with depressed flight trajectories, the forward-positioned dirigible can improve early-warning time and serve as a platform from which to fire counter weapons while the missiles pass through their boost phase when their low speed and large infrared signature tend to make them vulnerable.

"For underwater surveillance, the airship could emplace large fields of moored sonar buoys, monitor them, classify and correlate detections, and vector forces to localize and attack unfriendly submarines. The dirigible itself could carry antisubmarine warfare (ASW) support forces made up of aircraft or remotely piloted vehicles (RPV). Buoys that fail or break away would be recovered, replaced, and repaired, if necessary, in on-board maintenance facilities. The ships could retrieve and redeploy entire buoy fields.

"The airship could also tow horizontal linear passive sonar arrays, designed with an extremely large aperture, essentially to the limits of the sea environment. Screw and hull noises would no longer interfere with listening, and sweep rates and other performance aspects could improve. Subsurface arrays towed by airships seem specially suited to maintain surveillance over potentially unfriendly ballistic missile submarines.

"The Navy is replacing dedicated ASW aircraft carriers by the CV with its mixed complement of ASW and attack aircraft. The airship could bring about a return to a single-mission ASW carrier, and most important from a logistic and operational viewpoint, without needing accompanying destroyers or underway replenishment groups.

"Finally, the airship appears eminently qualified to serve as the central command post and operational control center for a designated sector of open ocean. It has the size to house the most sophisticated communication equipment, computers, and analysis and display equipment required by a major fleet command. Its mobility would permit the area commander to remain literally 'on top' of the situation.

"The dirigible could and should play other significant roles but space does not allow discussing them here. Oceanographic work for one. Use as

38-266 O - 74 - 9

a movable VLF antenna for communicating with submarines for another. A carrier and mother ship to Deep Submergence Rescue Vehicles for still another.

"The Soviets reportedly have an interest in using airships to deliver to the Siberian interior whole prefabricated buildings and completely assembled heavy equipment, and to bring out the region's natural wealth on the return flight. In March 1972 the Russian popular magazine *Sputnik* contained two articles on the subject. One stated that 14 Soviet institutions, including some government ministries, favor the building of large airships. The U.S. and USSR have formal cooperative programs in space, including a renedezvous in orbit. A new bilateral agreement, this time for the mutual development of airship transportation, would strengthen technical collaboration between the two nations. The Administration in its desire to see trade, understanding, and friendship developed between the U.S. and USSR, might well consider the airship as a tool toward realizing that goal.

"In addition, the government should look deeper into the 'disaster relief airship.' Creating it as a major international effort with internationally shared funding seems a 'natural' as does operation under United Nations auspices.

"While discussing the dirigible's international future, let us not forget Japan. Geographically isolated and dependent upon overseas commerce, the industry of that energetic country that produces the world's largest tankers may suddenly discover in the airship the means to transport manufactured goods rapidly and in bulk to Western Europe and South America. The discovery could work either to the distinct advantage or disadvantage of the U.S. aerospace industry.

"How much will it cost to build a *fully-equipped operational prototype* to do some of the tasks described above?

"Naturally that answer depends upon the size, performance, mission, and type of construction. Also upon the extent to which major subsystems (powerplants, for example) already exist and need not be specially developed. And upon the nature and extent of structural testing required (a large airship and a 'jumbo jet' might receive quite different treatment in this regard). Estimates for such a prototype range from as low as $100 million to as high as $500 million, with follow-ons, of course, substantially less. Six cargo airships, each 12,500,000 cu. ft. and of modernized conventional rigid airship design, could cost about $25 million a copy.

"But first, a training airship must be constructed. Exceptionally thoroughgoing flight and ground-handling proficiency building programs must forestall operating inexperience, a major cause of the lighter-than-air accidents of yesteryear. Simulators will help but they are not enough. The expertise and skills of flying large dirigibles have to be revived, starting anew. Before a crew can take over a large operational airship, it must at the very least have received a checkout in a smaller ship—probably of about 3-million cu. ft.

"This training ship would cost perhaps $50 million. It need not carry the advanced electronics and other special features required by the operational ships. Constructing such a ship inside one of the half-dozen dirigible hangars still standing in the U.S. would take about three years.

"Providing a training airship, an operational prototype, and qualified crews would probably cost too much for any private organization. Government support seems almost certainly required, particularly if the aerospace industry persists in some of its costly ways of doing things (often at the insistence of the government itself). The 6.5-million-cu. ft. *Akron*, an operational prototype, cost $5.4 million and its sister ship, Macon, $2.5 million. These two dirigibles, representing perhaps America's single most ambitious aircraft construction project of the late 1920s and early 1930s were built by a contractor's engineering group that, including draftsmen, numbered no more than about 50 persons. The Navy's highly successful ZMC–2 metalclad, a radically different developmental airship prototype involving new materials, design, and construction techniques, was engineered by a staff of a half-dozen. How many scores or hundreds would work on that same job today?

"Which agency might provide the support? The Coast Guard, Environmental Protection Agency, Geological Survey, Atomic Energy Commission, Arms Control and Disarmament Agency, National Oceanic and Atmospheric Administration, and, of course, the Maritime Administration all have programs and missions that would benefit from large airships. Individually, none of these Federal agencies would likely underwrite development alone. But they could

pool their requirements and resources and sponsor the ship collectively. One, however, must take the lead.

"The Defense Department could obtain the resources to begin a comprehensive airship program. Despite the military applications described earlier, DOD has so far shown little interest. If it does, an Air Force or Navy airship program could lay the foundation for nonmilitary usage and designs.

"NASA has apparently no more interest in airships than does DOD.

"Yet the airship offers a vast potential for services, applications, and uses important, even critical, not only to the U.S. but also to the world. It would have a measurable impact on the balance of trade, scientific progress, national defense, and international humanitarianism. It offers as much as did the SST—perhaps even more—an opportunity for engineering creativity, technological advancement, and *management innovation.* Building a dirigible differs from building an airplane. To revive airships, we must make a new technological start. *And in so doing, we can also make a new managerial start,* something much longed for by those caught up in the way of doing things that has evolved since WW II. Building a dirigible can be used by astute managers in government and industry to reverse the trend toward ever more costly and more difficult to control aerospace programs.

"Will the airship be revived? Almost certainly it will but not until its technical and operational merit has become more widely recognized and the subject itself given more professional attention.

"The time table could change overnight if the Office of Management and Budget concluded that airships can substantially or uniquely contribute to the Administration's goals at home and overseas. An OMB recommendation to develop this environmentally clean and attractive vehicle for its commercial, scientific, defense, utilitarian, and global good-will value is what is really needed.

"There is no question about *whether* the dirigible will return, but *when.* And that depends on how rapidly an awareness of its potential can be conveyed to the Executive Branch, Congress, the military, the scientific community, industry, and the public."

[Reprinted from Congressional Record, May 20, 1974]

Senator Goldwater on Airships

Mr. Bartlett. Mr. President, on May 13, the distinguished ranking minority member of the Aeronautical and Space Sciences Committee addressed the 36th annual meeting of the Aviation/Space Writers Association in Washington, D.C. His subject was "Airships?"

The Senator from Arizona said that transportation problems in the United States may shortly become so critical that the Nation will have to look at dirigible-type airships to help ease the crunch.

Moreover, he told his audience some of the thoughts that occurred to him in the wake of the energy crisis and the shortage of boxcars and transportation problems that are afflicting a growing and more demanding population. This speech raises an important question for the future of the Nation and I commend it to my colleagues.

Mr. President, I ask unanimous consent that the remarks of the distinguished Senator from Arizona be printed in the Record.

There being no objection, the statement was ordered to be printed in the Record, as follows:

"Airships?

"Thank you for inviting me to speak before the 36th Annual meeting of the Aviation/Space Writers Association. It is a great feeling to be among so many friends.

"Over the past 36 years there has been a lot to write about:

"Aviation played a decisive role in a global war.

"Routine air travel was established across the oceans and around the world.

"The sound barrier was broken and supersonic flight became routine.

"And man set foot on the moon.

"The advancement in technology has been staggering and the benefit to mankind incalculable. The writing professions have been an integral and necessary part of this saga.

"This morning I would like to share a few thoughts with you concerning airships.

"During the past year, there has been renewed interest in blimps, dirigibles and hybrids. It might be called a lighter-than-air-boom. Articles have appeared in large circulation magazines and in specialized professional and trade magazines. The term 'Helium Horse' was coined.

"A growing awareness of ecological and energy problems in transportation may be partly responsible for this resurgence. A sentimental journey by Americans back to the decade of the 1930's may have contributed. And, then, there is man's natural desire to find better ways of doing things.

"At the outset, we must recognize technical problems which are generally common to lighter-than-air vehicles: First, there is the basic problem of mooring a neutrally buoyant vehicle. Second, ballasting requirements during load transfers. Third, the fact the aerodynamic thrust is small—compared to potential gust loading—and is generally not vectorable for adequate station-keeping.

"Let us have a look at some of the apparent advantages of airships as compared to conventional aircraft:

"1. Outsized and heavy payloads can be lifted.

"2. Less pollution resulting from lower power requirements.

"3. Public annoyance reduced through low noise levels.

"4. Stay aloft for extended periods of time.

"5. Operate where there are no airports.

"6. Hover for extended periods of time especially in a hybrid mode combining static and dynamic lift.

"7. Safety resulting from sizeable mass and slow speeds. The foregoing characteristics suggest some intriguing applications.

"The Navy could certainly use airships for improved anti-submarine capability. Airships have a much better station-keeping ability than the conventional aircraft now used for submarine detection. Moreover, the airship could overtake or outdistance existing nuclear submarines, which most naval surface vessels are unable to do.

"The Air Force might use a fleet of airships as a launching platform for intercontinental ballistic missiles with the obvious advantages of dispersal and station-keeping.

"The civilian economy might be helped by the ability of the airship to carry huge and outsized payloads. Entire homes and buildings might be moved from factory to construction sites. Whole tree farming could become a reality. Heavy machinery for oil well drilling could be lifted to remote areas.

"Within the past few days, the Navy let a contract for $85,000 to the All American Engineering Company of Wilmington, Delaware to study a concept known as the Aerocrane.

"Aerocrane is a hybrid vehicle which looks like a spherical balloon with four rotors attached 90 degrees apart. The balloon part of Aerocrane has a diameter of 150 ft. Each rotor is 112 ft. long. On each rotor there is a turboprop engine developing 1250 horsepower.

"The entire vehicle turns at 10 revolutions per minute with a tip speed of 196 ft. per second. Forward operational speed would be a maximum of about 52 miles per hour. Favorable weather conditions are required.

"Aerocrane is said to combine the advantage of static and dynamic lift, and the small version would be able to lift a 50-ton sling load. A later stretch version would be able to lift as much as 200 tons.

"The Navy believes a vehicle like Aerocrane could help with small craft and aircraft salvage, ship repair, submarine rescue operations, amphibious assault, and harbor improvement. Navy planners have to take into account political instability in much of the world, which can make the future availability of a specific port questionable.

"Since 1972 Aerospace Developments, Ltd. of London has been working on a giant airship under contract to the Shell Oil Company.

"When I say giant, I mean an airship 1800 feet long, 300 feet in diameter, and with a 100 million cubic feet capacity. (I don't know who started the rumor that the British think small.)

"The purpose of this vehicle would be to transport natural gas in a gaseous state.

"I understand that Shell Oil Company is satisfied with the economics of this airship. As you no doubt know, the cost of a liquid natural gas plant is

upwards of $100 million. The cost of a liquid natural gas plant is upwards of $450 million. When you combine the ship and the plant costs Shell believes the airship will show a savings of at least 30%.

"Nationalization, the threat of nationalization, and political instability are making the oil companies reluctant to make capital investments where these conditions exist. A giant natural gas airship is a neat solution.

"Shell's determination is simply demonstrated by its instructions to Aerospace Developments. These instructions say in effect: Keep going until you run into a technical problem you can't solve.

"In 1973, there were 40 nuclear power plants in operation. According to one industry estimate, there will be 150 units in 1980, and the curve will rise to 1000 units by the year 2000.

"In the past, nuclear power plants had to be located near large bodies of water for cooling purposes. With improved cooling tower technology, nuclear power plants can now be located away from lakes or rivers.

"But, there is a transportation problem. Components in the 50–400 ton range must be moved from the factory to the plant site. Where the components can be barged by water all is fine, but what happens if the plant site is inland?

"It is a fact that Combustion Engineering of Hartford, Connecticut, has entered into an agreement with a large aerospace company to jointly study the airship as a way of moving large nuclear plant components.

"Clearly commercial markets for airships can be identified—markets where there is a need to move large, bulky cargo.

"There may be another market—one that is hard to identify. But, ask yourself this question:

"How many of the things we manufacture are limited by constraints which we take for granted?

"I don't mean to tell this audience about the weight and size limitations of air cargo.

"But let's take a look at the more mundane surface transport constraints.

"If you are moving cargo on a railroad, you are limited by the size of a flatcar which is 89 ft. 4 in. long by 10 ft. 8 in. wide.

"Moreover, your railroad flatcar has to go through underpasses that are 22 ft. high by 16 ft. wide. But that's not all. Your cargo will have to pass through railroad tunnels that have a vertical wall height of 15 ft. 7/8 in. to which you can add 6 ft. at the arch center.

"If you're moving cargo by truck you are going to be confronted by 14 ft. underpasses near cities and 16 ft. underpasses in outlying areas. Moreover, you'll find width constraints averaging 12 ft. depending upon the areas.

"Nearly everything that flies from an airport is subject to the same constraints.

"It doesn't take much imagination to see what might happen to the economy. if the weight and size constraints built into our surface transportation system were removed.

"There are only two ways to get around the underpass and tunnel problem: barge and aircraft.

"Further, ask yourself this question: How are we going to build houses, pipelines, power plants, office buildings, ten or fifty years from now?

"I don't think we will be building houses by attaching lumber, nails, pipe, and siding at the building site—and, then putting it all together piece by piece.

"Again, part of the answer has to be aviation.

"While airships have been enjoying renewed interest especially in the past year, it behooves the prudent to cast a wary eye.

"Airships have both technical and political problems.

"The technical problems involve first of all economics which don't appear to be fully understood today, or at least, not by me. For example, I have heard cost per ton mile figures ranging on the low side from one cent to 45 cents on the high side. There seems to be a very definite need to refine economics of airship transportation.

"On the engineering side, there are problems concerning materials, attitude control, and landing.

"When the *Hindenburg* landed at Lakehurst, New Jersey, on May 6, 1937, a ground crew of 230 men was needed—most of them to handle mooring lines. I doubt that this method of landing would be acceptable in 1974, because of the huge cost involved—not to mention consternation among the next of kin.

"And the bureaucrats who administer the Occupational Safety and Health Act would have a field day.

"On the political side, or if you prefer, the PR side, there are two factors that stand out:

"First, the poor reputation of dirigibles resulting from what might be called the *Hindenburg* syndrome.

"Second, what might be termed the giggle factor—which means what happens to you when you mention dirigibles to those who think they won't work.

"The picture of the *Hindenburg* going up in flames is firmly etched in the memory of anyone old enough to have seen the newspaper pictures. It was a terrible disaster, but as you know, it resulted from the fact that the Germans had to use hydrogen for lift.

"Detractors of lighter-than-air technology point out that the zeppelin had great difficulty in operating in foul weather. They correctly point out that success of the zeppelin was as much a result of the high quality of the skippers as of the craft's essential airworthiness.

"But, let us look at the other side of the coin:

"The zeppelin's skipper had no on-board weather radar.

"He couldn't take advantage of space-age weather forecasting.

"His airship was under-powered.

"He had to have a crew continually adjusting and repairing his craft.

"He was denied the safety of helium.

"With modern materials, avionics, and propulsion—unknown in the zeppelin days—I believe a dirigible could be built that would be at least as safe as existing fixed-wing aircraft. Economics is the driving consideration.

"The 'giggle factor' is harder to counter, because it is based on a gut reaction.

"I can understand why some people feel that blimps are ludicrous. They are big, and they are slow.

"To some extent, the 'giggle factor' is abetted by those who have a romantic interest in lighter-than-air. Some exaggerated claims, backed by skimpy technical information, have been made for dirigibles.

"For example, I don't see the United States government or private industry financing a R & D effort in airships to take passengers on moonlight cruises up the Amazon River. On the other hand, the romantics have proposed that large airships could be used to take entire hospitals to disaster areas. That strikes me as an idea worth considering.

"If passenger airships ever come about, I believe it will be an adaptation of an airship developed for other purposes.

"Meanwhile, let's not kick the romantics around. The tremendous strides made in aviation is partly attributable to their dreams—without their dreams it might never have happened.

"Airships deserve a second look for the promise they hold in meeting real transportation needs. If our national aeronautical R & D effort is to merit public support, part of the effort must be devoted to meeting the discernable everyday needs of people.

"If our Nation has a chronic boxcar shortage, what can aviation do about it?

"If better and more efficient methods of distributing goods are needed, how can aviation help?

"A clue in solving our transportation problems may be found in looking at the total system. What are the choke points? What are the artificially created constraints? What needs to be done to overcome them?

"In the overall picture, airships are likely to be only a part of the future aeronautical R & D required by the Nation. To meet our future needs:

"We must push advanced propulsion.

"We must build modern aeronautical research facilities.

"We must pursue research in supersonic and hypersonic aircraft.

"We must put as much emphasis on performance as we do on pollution and noise.

"The economic and spiritual well-being of the Nation demand that we push the frontiers of knowledge and technology. Through our renewed commitment to doing a better job, we can assure a healthy aerospace industry.

"Most important of all, we can provide a better and fuller life for all Americans.

"Thank you."

[Reprinted from Congressional Record, May 29, 1974]

THE INDESTRUCTIBLE BLIMP

Mr. GOLDWATER. Mr. President, as a result of an address I made to the 36th annual meeting of the Aviation/Space Writers Association concerning airships, some mail has been coming into my office on this subject.

The most unusual letter came from Lt. Comdr. Gillis Cato, Jr., U.S. Navy Reserve, retired. He took part in a blimp trip that can only be described as incredible. In a period of about 2 days, he crash landed three times: Into Lake Pontchartrain, on top of an automobile, and in a forest. Moreover, his airship managed to knock out the entire power system of Houma, La.

Lieutenant Commander Cato's narrative demonstrates one important point about airships: Their inherent safety.

Mr. President, I ask unanimous consent that the Cato correspondence be printed in the Record.

There being no objection, the correspondence was ordered to be printed in the Record, as follows:

OCEAN SPRINGS, MISS.,
May 15, 1974.

"Hon. BARRY GOLDWATER,
"*U.S. Senate, Washington, D.C.*

"DEAR SENATOR GOLDWATER: A couple of days ago I heard a commentator state that 'Senator Goldwater is now advocating the building of dirigibles.'

"This was said very much tongue in cheek. I do not believe he would have been so flippant if he had taken the time to have looked up a few facts on lighter than air transportation.

"I believe my background qualifies me in some small way to comment. Briefly it is as follows:

"During world war two I was assigned to lighter than air after I was thoroughly grounded in the ways of airplanes. This, of course, was to be expected. Naturally this did not endear me to blimps. However, after a thorough study of them at Lakehurst, N.J. I was then assigned as engineering officer to commission the station at Hitchcock, Texas, after which I was sent to Rio as engineering officer in charge of LTA over-haul for the whole Atlantic area from Trinidad to Rio. As you may imagine, I had plenty of time and opportunity to become thoroughly acquainted with all of the vagaries of LTA. One of my very first assignments upon reaching Brasil was to salvage a blimp which had smashed headon into a mountain about a hundred miles north of Rio. Having had considerable experience with the unpleasant details of salvaging airplanes, you can imagine my surprise when I found that of the whole crew the worst injury consisted of a sprained ankle. My respect for LTA began to grow.

"While in Hitchcock, Texas, I had a chief whose name was Hamilton. He was on one of the dirigibles which came apart earlier and much before world war two. He told me in detail exactly what happened. He said that for no reason at all the pilot flew the ship directly into a very severe thunderhead. This is something you avoid even with a 707. He then told me that he believed that even then they would have made it except that these dirigibles which had been made in Germany by people who knew their business, had been drastically altered. It seems that the Germans put a very strong and rigid keel in each of the dirigibles they built. An Admiral who shall be nameless decided that he knew more than the Germans and that in order to save weight, had the keels removed from all the dirigibles the Germans had designed and built. The results are too well known to dwell on here. However, it is most noteworthy to observe that even when these ships broke apart several thousand feet in the air, few of the people were killed, by comparison with any airplane in like circumstances in which nobody would possibly survive. The Chief told me that he and many of the men with him floated down to the sea in the after end of the ship due to the compartmentation of the gas bags which provided the lift. There was no fire and no explosion.

"Much has been made of the burning of the Graf Zeppelin.

"There was one reason and one only why this ship burned. Hydrogen.

"If we had given the Germans helium I would not be surprised if the ship were still flying. Very little is said of the flights this ship made at a time

when we were still flying biplanes. She very casually roamed all over the world with no danger or even an untoward incident. Proof that the Germans thought they had something big lies in the fact that they built a huge hangar, very permanent construction, just outside Rio. I used this hangar all the time I was stationed there.

"While engineering officer in Brasil, I had many chances to observe some unbelievable trips that these craft made that served to demonstrate their toughness. My job demanded that I fly these ships at least twice a week and it was after a couple of trips in them that it dawned upon me that if a person wanted to fly that was the way to go. The advantages are obvious:

"Enough speed to go any place, but slow enough to see everything there is to see, which is why most people travel anyway.

"No need to fly thirty thousand feet. Fly two hundred if you choose in perfect safety and with unparalleled visibility.

"Comfort; plenty of room to move about, even in a blimp. In a dirigible room enough to run a footrace.

"As to fire; it is obvious that the only sensible power for a dirigible would be diesel engines with fuel that is hard even to set fire with a match.

"While in the service I, with the aid of others in the engineering departments, worked out various designs for rigid ships. I believe that a flexible frame is easily possible which would save weight and at the same time be able to give when the occasion arises. An interesting side note: If a LTA craft is caught in a 150 knot wind a person can lean out the window and hold a lighted match. The reason of course is that it travels with the wind instead of fighting. Makes for a some what longer but very interesting and safe trip. Try letting a 747 drift with the wind.

"I am enclosing a copy of an absolutely true trip I personally took in a blimp. I wrote this up for a few friends after telling them about it. I believe it will serve very well in demonstrating the indestructability of a LTA craft.

"I sincerely hope that you were not being facetious when you mentioned the construction of a rigid airship.

"Nothing would give me more pleasure than to be able to use some of the knowledge I have accumulated about LTA and to be associated with such a project.

"Very truly yours,

"GILLIS CATO, JR.,
Lieutenant Commander, USNR, retired."

"THE INDESTRUCTIBLE BLIMP

"It was only natural that after enlisting in the Navy in 1942 with a thorough knowledge of airplanes, that I would be sent to Lakehurst, New Jersey to become proficient in blimps.

"After a few months there I was made engineering officer of the Hitchcock Naval Air Station, Hitchcock, Texas. Following the usual trials and tribulations of getting a station commissioned, we were soon in the business of flying the big airships on submarine patrols.

"One night about twelve o'clock I was called to the base to find that we had apparently lost three blimps. Frantic radio and radar search finally located and guided two of these back to the base. The third kept calling and saying he was west of the field and drifting. He finally got out of radio range and we all sat about eating fingernails and coffee. At nine the next morning we received a call from a civilian at Starkville, Mississippi, who stated that the blimp had landed there in a field, re-fueled with a regular gas, and took off after asking him to call. He stated that the blimp was at that moment circling the city of Starkville.

"We took a crew in a Liberator and headed northeast, not west, to find our blimp calmly going round and round the Mississippi State University. I was riding in the nose and signalled them to follow us to Columbus, Mississippi, air base. Inasmuch as I had, before joining the Navy lived at Greenville, Miss., this whole country was as familiar to me as the palm of my hand.

"We landed at the air base, recruited a landing party to haul the blimp down, drained the tanks and re-fueled with aviation gas. With the blimp

safe and apparently in perfect condition, the question now arose as to what to do next. The obvious solution would have been, get aboard and go to Texas. Two things stopped the obvious; the crew who flew it to Columbus stated flatly that they did not intend to fly again for at least a week. The second thing was the weather report. While the sun shone brightly at Columbus the weather man said the birds were walking from Hattiesburg south on account of the fog and all planes were grounded.

"We had brought along a LCDR, a JG., a flight mechanic and me, the good old engineering officer. If I would agree to fly we could take off with a short crew. Not being bright I agreed to fly.

"The weather deal was easy; all planes were grounded, we were not a plane, simple—we would fly to Texas in a pea soup fog and demonstrate a masterly piece of navigation.

"We took off at about four in the afternoon. The LCDR kept the blimp about ten feet above the trees and asked for the antenna to be lowered so he could notify all and sundry that we were on the way. The antenna bob struck a limb and bounced up into the gas bag aft cutting a hole about two feet long. The LCDR stated he was not getting reception. I told him where the antenna was. He said take the crook and pull it back out. I did and it promptly went into the bag again cutting another hole. He then said to heck with the whole business as we would be there before they knew we were coming.

"The weather was still clear and shortly after this we flew over a large barn at our tree top altitude. Several things occurred; all the chickens took off and vanished. The livestock in the barn lot left, taking the fence along. Those in the barn left also, taking the sides of the barn along. The apparent owner was walking across the lot with a shotgun. He let us have both barrels. A blimp hide is very tough and the small shot had no effect. Buckshot might have written a different ending to this narrative.

"The weather began to show evidence of the predicted fog and I decided that I might as well sleep through the whole thing and I sacked out. An hour or so later I was awakened and the LCDR asked me if I could tell him where we were inasmuch as I knew the country. I looked out and had a glorious view of nothing. Even the engines were invisible. Whoever said the birds were walking was not kidding. The LCDR said they had passed over lights a few minutes back. I assumed these were Hattiesburg, Miss. since the time element was about right. The LCDR said that it made no difference as he had computed a course that could not miss. About two hours later we sighted a light in the soup and the LCDR said that he had it figured right on the nose as that was the light on the hangar at Houma, La. I looked at the altimeter and it said we were at about 600 feet. The hanger had either grown or the altimeter was way off. Something gnawed at my subconscious. As we circled the light again close enough to touch it, it hit me. I yelled, 'Get the hell out of here, those are the radio towers in New Orleans and they are made of very good steel.'

"We promptly went up and out of danger. Take LCDR, said he guessed we had better make another calculation on our navigation. I thought we had better get a Texaco road map and a flashlight. We then figured we could not miss anything as large as Lake Pontchartrain and headed in that direction. After due running time we decided to let down, be sure of the lake and then calculate from there. We let down, and down, and down. Just as the altimeter hit a hundred feet we hit the lake. Water came almost to the deck but since so much weight had been relieved by the water the gas bag promptly hauled us up again spouting water from every seam like a ruptured whale.

"After a profound interval of silence the Fight Mechanic allowed that he believed there was no doubt that we had found Lake Pontchartrain. The LCDR perked up, said he had it down pat now, and we could take off for Texas. Everybody disagreed and insisted that we first find the Mississippi River, but not exactly as we had Lake Pontchartrain. He agreed and we set off, very carefully timing our flight. At what we hoped was the proper time, we very carefully descended. Miracle of miracles, we popped out of the fog right over Old Man River. Now it was easy enongh to find the Huey P. Long bridge and follow the road to Houma. We could put down there for the night and wait for better weather.

We found the bridge, lined up on the highway and headed west with all signals go, and made in the shade—we thought. There was a car going the

way we wanted to go and his lights made it all the nicer. Meanwhile, back at the ranch—The blimp had been slowly losing helium from the antenna incident. In addition the bag was loaded with about 2700 pounds of moisture from the fog. The controls were logy and when she was pointed down she wanted to keep on down and would mush for awhile before answering the elevator. The LCDR was determined to keep the car in sight. He was doing so but getting dangerously low. Suddenly the old girl decided to keep on mushing down and did so, right on top of the automobile. No one will ever know what he thought. He ran off the left side of the road and vanished. Apparently no injury was incurred as we never heard of him again. We turned sideways across the road and went off to the right into a huge grove of soft feathery willows. The blimp rolled to one side as if it was tired of the whole thing and wanted to sleep. During this time we were also being treated to some rather startling pyrotechnics. Fire was flying all over the car and even way back on the afterpart of the bag. We had not time to even speculate on these happenings as we were waiting to see what would happen to the blimp. As in the Lake Pontchartrain landing, the weight being off and absorbed by the willows, the bag yanked us back into the air. The jar had relieved us of a lot of water also. We circled gingerly back to the road and continued west. The controls were nearly impossible. Something had happened but we would not know what until much later.

"I remembered two tall brick chimneys at Raceland at the sugar mill and they were too close together to fly through. I had no desire to wind up stuck like a hog in a fence. The LCDR decided to rise a bit higher. We did, and promptly lost sight of the road and everything else.

"We had been calling Houma Naval Air Station for some time with no reply, but we knew we would be able to see all the lights at Houma. Calculating our speed and the known distance we soon knew we had to be over Houma. Not one light was visible. Again the slow, careful descent. This time we were lucky, we did not hit the ground, we only ran into the water tower at Houma. The crash of breaking nose battens informed us that we had better not place any confidence in any landing lines attached to the forward part of the blimp. We had no way of knowing whether or not all landing line had been carried away. The LCDR then did the first constructive thing on the whole flight. He went up to three thousand feet and stayed there.

"With daylight we were treated to a sight of the world without fog, and in addition we were right over the air training station at Lafayette, Louisiana.

"The blimp was now as heavy as lead and we knew we would not need a crew to pull it down so we decided a landing was in order. The one we made was without a doubt the hottest one a blimp ever made. We took up the whole landing strip. Usually a blimp lands in about a hundred feet and has to be hauled down.

"The cadets poured out to see the 'monster' and we were subjected to some remarks about idiots that fly in bags and a few that cannot be printed here. We ignored them and inspected the blimp. It was so heavy from helium loss that the one landing wheel tire was spread out two feet wide. The control difficulty was easily assessed. The trouble was a thirty foot willow tree that had become entangled in the control cables and had been pulled up by the roots by the blimp. Since a blimp is about as tall as a five story building the tree just had to stay there until we got to home base.

"The station gave us a magnificent breakfast, full tanks of gas, bowed their heads in prayer for our safe return, and saw us off. A blimp has dynamic lift like an airplane as well as lift furnished by the helium. Without it we would have never got off. As it was we used up every bit of the runway and for awhile it appeared we might pick up another willow or two. The trip to Hitchcock was uneventful. The landing was somewhat difficult as we had become even heavier. We jettisoned our depth charges, all movable gear, and dumped all the gasoline except enough to land on.

"The most unbelievable part of the whole deal, and every word is true, is that that damn blimp was out on patrol next morning. That is more than can be said of the crew.

"To summarize: the fireworks we experienc were simply explained. We had run through a 440,000 volt high power line and demolished it. It in turn melted off our tail wheel, burned holes all over the car and burned deep grooves in the propellors.

"Knowing this, it was easy enough to see why we could not find Houma or the Naval Air Station there. We had blacked out the whole area of that part of Louisiana. We heard later that a perennial drunk had been sleeping it off under the tower at Houma. It is said that he has never touched another drop. Much later, as I was going overseas, I talked to a Chief of Communications who had been stationed at New Orleans on that wild night. He told me that they had been ordered to close down except for a standby watch and go home as nothing would be flying. He said that a bunch of damn fools in a blimp had put a stop to all that and kept the whole communications system up all night on emergency. He said that if he ever saw one of the crew he would strangle him and believed he would be justified. I agreed."

Senator GOLDWATER. The next witness will be Dr. Jerry Grey, accompanied by Mr. Ernest Simpson of the Air Force, Aeropropulsion Laboratory, who will present testimony on advanced aircraft propulsion systems.

I am sorry, did you have a question?

Senator BARTLETT. No.

Senator GOLDWATER. I get so lonesome in here I sometimes forget.

Senator BARTLETT. You did fine.

Senator GOLDWATER. You may proceed.

[The biography of Dr. Grey follows.]

BIOGRAPHY BRIEF FOR DR. JERRY GREY

Dr. Jerry Grey received his Bachelor's degree in Mechanical Engineering and his Master's in Engineering Physics from Cornell University; his Ph. D. in Aeronautical Engineering from the California Institute of Technology.

His early career included stints as a full-time Instructor of Thermodynamics at Cornell, an engine development engineer at Fairchild, a Senior Engineer at Marquardt, and a hypersonic aerodynamacist at the GALCIT 5" Hypersonic Wind Tunnel. He was a professor in Princeton University's Department of Aerospace and Mechanical Sciences for 15 years, where he taught courses in fluid mechanics and propulsion and served as Director of the Nuclear Propulsion Research Laboratory. He formed the Greyrad Corporation, a supplier of high-temperature instrumentation, in 1959 and was its full-time President from 1967 to 1971. He is now Administrator of Technical Activities for the American Institute of Aeronautics and Astronautics, where he spends half his time; the other half is devoted to consulting practice, writing, and lecturing.

Dr. Grey is the author of four books and over a hundred technical papers in the fields of fluid dynamics, heat transfer, rocket and aircraft propulsion, nuclear propulsion and power, plasma diagnostics, instrumentation, and the applications of technology. He has served as consultant to the U.S. Congress, the Air Force, NASA, and the AEC, as well as over twenty industrial organizations and laboratories. He was Vice President-Publications of the AIAA for five years, and is listed in *Who's Who in America, American Men of Science, Who's Who in Aviation, Engineers of Distinction*, and the United Kingdom's *Blue Book* and *Dictionary of International Biography*.

STATEMENT OF DR. JERRY GREY, ADMINISTRATOR, TECHNICAL ACTIVITIES AND COMMUNICATIONS, AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS, ACCOMPANIED BY ERNEST SIMPSON, AIR FORCE, AEROPROPULSION LABORATORY

Dr. GREY. The AIAA appreciates this opportunity to present its views on advanced aircraft propulsion to this committee, and I thank you for your invitation to appear before you.

Before I proceed to the substance of our testimony, I want to point out that my appearance here today is as a representative of the Insti-

tute, and that the material I offer has been thoroughly reviewed by appropriate members of our technical committees. Appearing with me is Mr. E. Clifford Simpson, who served as chairman of the propulsion group at the recent AIAA Workshop Conference on Aircraft Fuel Conservation.

My testimony will be in three areas: advanced engine cycles, new fuels, and nuclear propulsion. As you have suggested, Mr. Chairman, I will devote my brief time here primarily to research and development opportunities which are either not yet included or are not yet I believe, receiving substantial emphasis in current Federal programs.

I do, however, wish to call to your attention a basic premise which, although not explicitly stated, is interwoven throughout my entire testimony: We face, in this country and in the world, an end to the virtually limitless availability of natural liquid petroleum-based fuels which we have enjoyed up to now. Although the recent "energy crisis" may appear to have been relieved, serious and perhaps even crippling fuel shortages are almost certain to reappear in the coming months and years. The search for viable petroleum substitutes, and for methods to reduce our fuel consumption until such substitutes become available in quantity, are therefore essential elements in all aeronautical research and development considerations. This subject was covered in some detail at a recent AIAA Conference on Aircraft Fuel Conservation which you, Mr. Chairman, strongly supported and which I have listed as one of the references in an Appendix to this testimony.

Senator GOLDWATER. Will you send a copy to the Committee, and we will make it part of the record.

Dr. GREY. Thank you; I certainly will.

NEW ENGINE CYCLES

Although the "jet age" may appear to be well into its maturity, many opportunities still exist for major performance, cost, and fuel-conservation improvements by tailoring engines, and their installation in aircraft, for specific purposes. At present, different propulsion systems are used for different operating conditions, but a new concept, the variable-cycle engine, shows great promise for efficient operation over a wide range of subsonic and subsonic/supersonic flight conditions. We have therefore chosen to discuss this concept in our testimony, although there are, of course, many other new engine concepts undergoing research and development, as you have heard in testimony presented to you by NASA and others earlier this year.

I have also decided to discuss briefly a far more advanced idea, the supersonic-combustion ramjet engine required for hypersonic aircraft propulsion. These two engine concepts were selected for our testimony from among all other possible choices because between them they incorporate many of the new features which we believe are the forerunners of tomorrow's propulsion technology. Both were mentioned in the NASA testimony on July 16.

VARIABLE CYCLE ENGINE

Mr. Goldwater, I heard you ask Dr. Fletcher for a paper describing this engine. One will be published in the AIAA's magazine, Astronautics and Aeronautics, next February. I have with me a preliminary copy of the basic content of that paper, which I will be glad to leave here with you.

Senator GOLDWATER. Thank you very much.

This concept is basically a variable bypass engine; that is, the fraction of the total airflow through the engine which passes through the fan, thereby "bypassing" the fuel-burning core of the engine, can be varied over a wide range. The basic advantage of this variable bypass flow is that it can provide the optimum bypass ratio for each flight speed. Also, it has the potential for substantial reductions of "installation losses" in both the inlet and nozzle. Thus, a variable-cycle engine can operate at peak efficiency from takeoff to high supersonic flight speeds.

Because this engine cycle requires a number of innovations in engine technology, it is still considered to be at least a decade from implementation in even a test aircraft. The principal developments needed are variable-pitch, variable camber fans (similar in basic principle to, but far more complex than, the familiar variable-pitch propeller), variable-area turbine inlet nozzles for both the low-high pressure and high-pressure turbines, variable-area convergent-divergent exhaust nozzles, and a propulsion control system capable of integrating all these variable-area components with the fuel control over all flight-speed ranges. Such further improvements as higher-pressure-ratio compressor blading, overall higher-pressure compressors, high-temperature (columbium-lined) combustion chambers, and in some cases regenerative heat recovery, are also important elements in variable-cycle engine development.

Along with a totally new approach to blending the engine into the airframe, these features permit the use of a single engine over a wide performance range. Just as the automobile has several gear ratios to meet the requirements of its use, the aircraft in many instances has the same opportunity to save fuel through discrete cycle changes for takeoff, climb, subsonic cruise, supersonic cruise, dash, and other operating modes. The variable-cycle engine thus can provide high-performance STOL capability and/or low-noise operation at takeoff and landing while still being capable of high-speed economical cruise flight, and it also permits efficient subsonic and supersonic performance by a single airplane.

The most imminent applications for this new engine cycle are military, which is why the Air Force is currently spearheading the effort. However, this Nation will, someday, be forced to reconsider the needs and the implications of a commercial supersonic transport aircraft, as was mentioned by both Dr. Fletcher and Dr. Cannon here on July 16, and the variable-cycle engine will become a major element in that reconsideration. For example, our now-defunct 2707 supersonic transport design used up a major fraction (about 30 percent)

of its fuel just to reach cruising speed, partly because its engines were, of necessity, designed to operate most efficiently at 2.7 times the speed of sound at high altitude. A high-bypass-ratio engine would have been much more efficient for takeoff, climb, and landing; further, it also happens to be the best configuration for least noise. This combination of requirements "makes the case" for the variable cycle engine in any future SST—and despite the continuing negative attitude toward SST's, we need to be doing our technical homework now to protect our valuable future commercial aircraft market against the possibility of a successful second-generation foreign SST.

But even if the variable-cycle engine does not find its home in a commercial supersonic transport or in advanced STOL/low-noise applications, or proves too difficult to develop as a complete concept, the above mentioned advancement in component technology which might be achieved during the development process will have far-reaching implications in all future engines, not the least of which, as was identified in the recent AIAA Workshop Conference on aircraft fuel conservation, would be substantial reductions—up to as much as 50 percent—in the consumption of fuel. We therefore ask that this committee encourage and support both engine and aircraft research activities associated with the variable-cycle engine concept, and we certainly concur with Dr. Fletcher's statement that this should receive the highest priority in any new funding consideration.

SUPERSONIC COMBUSTION RAMJET

The supersonic combustion ramjet finds it application even further in the future than that of the variable-cycle engine. A truly new concept, it is the only airbreathing engine which can operate effectively at flight speeds in excess of Mach 5.

The "Scramjet", as it is sometimes called, was pioneered by the Applied Physics Laboratory at Johns Hopkins University, was studied at a low level of effort for some years by NASA's Lewis Research Center, and is currently being pursued, also at a low level, at NASA's Langley Research Center. Like all ramjets, it can only operate at relatively high flight speeds. That is, in an ordinary turbojet, a compressor is used to achieve the pressure ratio needed to drive the burned hot gasses through the engine, whereas the ramjet utilizes the recovery pressure of the air "rammed" into the engine. In a conventional ramjet the air must be slowed up sufficiently by the time it reaches the combustion chamber, to reduce the pressure losses associated with turbulence and other dissipative processes of high-speed air flows. In a very high speed engine, however, this slowing-up process becomes too inefficient, so in the Scramjet the supersonic inlet air is slowed only partially. The inlet shock wave, although it isn't strong enough to reduce the air flow all the way to subsonic speeds, still generates sufficiently high air temperatures so that the engine can maintain a hydrogen-air flame even at supersonic air speeds.

Military interceptors and commercial hypersonic aircraft (HST) which might use this engine are still many years off, and require much research effort not only on the new engine concept, but also in aerodynamics, materials, and the aircraft cooling systems needed at flight

speeds in the Mach 6 to Mach 8 range. The two major attractions of the HST, other than its extremely high speed, are its reduced sonic boom impact—because of the extreme altitude at which it flies—and the fact that its use of hydrogen, the only fuel which makes the HST possible, avoids the need for scarce fossil petroleum.

From the viewpoint of this committee, support of research activity on the Scramjet at a low but steady level is important today, even though commercial or even military implementation of a hypersonic aircraft is not likely until the decade of the 1990's or even later. We make this suggestion because much of the aerodynamic, combustion, instrumentation, and materials knowledge needed for this highly advanced concept will maintain for the United States a strong "cutting edge" of airbreathing propulsion technology which will be reflected throughout the entire spectrum of aircraft applications, both in the immediate and distant future. The sustenance of such advanced technology programs has in the past proved its worth in providing the technical base which has kept the United States well ahead of the rest of the world in both commercial and military aircraft, a not insignificant factor in our international economic and military survival.

NEW FUELS

We in the aircraft field are particularly sensitive to the ever-growing specter of scarcity—and hence ever-increasing cost—of petroleum-derived fuels. Perhaps no other transportation system or energy-consuming segment of modern industry is quite so dependent on the availability of liquid petroleum. It is therefore of critical importance that we begin to establish alternate fuel capabilities immediately, because of the very long lead time necessary to implement such capabilities into commercial and military aviation.

Of the various alternatives we might consider to replace or supplement petroleum-based fuels, there are only three basic categories: more or less conventional liquid hydrocarbons derived from coal or shale-oil, synthetic hydrocarbons, and totally new aircraft fuels such as hydrogen or methane. In all cases, there are two possible extremes in approaching the use of new fuels: either develop a fuel which can be used in existing engines, or modify the engines as necessary to accommodate the fuel. In practice, a combination of these two extremes will almost certainly be pursued.

HYDROCARBON FUELS

A small "first step" in the process of introducing coal-derived liquid hydrocarbon fuels has already been initiated by the Navy, which has undertaken a test program to evaluate their compatibility with current military specifications. However, although such fuels are readily available in laboratory quantities, there is at present no capability in the United States for making available aircraft fuel cuts derived from coal or shale oil in sufficient quantities—that is, more than pilot plant amounts—for an adequate engine testing program. Since these fuels are likely to be most economically useful if some departures from present petroleum-based fuel spcifications are

permitted, such testing of modifications on at least a few different types of engines will be essential. We therefore suggest that this committee support the immediate implementation of a small-scale production program directed specifically at the manufacture of aircraft fuels from coal and shale oil. We make this recommendation in the belief that the prospects for practical utilization of any alternative fuels other than fossil-derived liquid hydrocarbons are considerably further downstream in time.

[The table follows:]

POTENTIAL NEW FUELS FOR AIRCRAFT

Fuel	Heat of combustion (L)		Density lb/ft³	Boiling point	Specific heat, Btu/lb/F	Cost, dollars per 10⁶ Btu
	Btu/lb	Btu/ft³				
JP (jet A)	18,590	940,000	50.5	370° F, to 550° F, liquid at normal temperature.	0.47	$1.00–$3.00
Hydrogen LH_2	51,500	222,000	4.3	—423° F cryogenic	3.20	2.50–8.50
Methane LCH_4	21,500	570,000	26.5	—259° F cryogenic	.49	1.50–3.00
Propane C_3H_8	19,940	720,000	36.1	—44° F, low temperature or compressed gas.	.65	.75–2.00
Methanol CH_3OH	8,640	426,000	49.4	149° F, liquid at normal temperature.	.60	1.00–2.00
Boron (type B_5H_9)	30,000	1,188,000	39.6	137° F, liquid at normal temperature.	.57	100.00–300.00
JP from coal	18,830	996,000	53.0	370° F, to 550° F, liquid at normal temperature.	.47	1.50–3.00
Nuclear						

Dr. GREY. In the very long term, of course, the demand for even coal-derived hydrocarbon fuels will become excessive, especially when they come into wide general nonaviation use, as they certainly must. We in the aviation field will then be faced with the need to manufacture synthetic fuels by utilizing nonfossil energy sources, for example, nuclear breeder reactors and, hopefully, nuclear fusion and solar power. The two general classes of such synthetic fuels we might consider are liquid hydrocarbons, very much like the fossil-derived fuels in use today, or cryogenic high-energy fuels such as methane or liquid hydrogen.

Conventional hydrocarbon fuels could be synthesized, with sufficient availability of energy, from carbon in vegetable matter, natural limestone—calcium carbonate—or even the carbon dioxide in the atmosphere combined with hydrogen obtained from water—for example, by electrolysis. Advantages of these hydrocarbon fuels are the same as those in use today; their high energy density—energy per unit volume—and no requirement for sweeping new technology or logistic distribution systems. Their disadvantages, as compared with hydrogen or direct nuclear propulsion—which I will discuss later—are their lower energy content per unit mass and, possibly even more important, their higher levels of air pollution. The relative cost of these fuels is, of course, perhaps the critical factor, but we do not as yet have any basis for establishing such cost data. Thus my recommendation for pursuit of this avenue for new fuel development must be made in the light of those for other alternative fuels, as is given later in my testimony.

LIQUID HYDROGEN

The potential for using liquid hydrogen as an aircraft fuel has been considered extensively in the past few years, both by NASA and by a number of industrial groups. Its principal benefit is its very high energy per unit mass, which can provide substantial improvements in range over hydrocarbon-fueled aircraft. Hydrogen also generates very low air pollution levels, and affords an opportunity for avoiding the use of scarce petroleum-based fuel—coal is an excellent near-term source for hydrogen. Principal disadvantages are its low energy density—energy per unit volume—and low temperature, which demand very large, well-insulated aircraft tankage, its high cost as compared with present or even projected shale oil or coal-derived fuels, and, perhaps most important, the lack of a nationwide logistic system for liquid hydrogen manufacturing and distribution. Its future cost as compared with true synthetic hydrocarbons, based on utilization of nonfossil energy sources to manufacture both classes of fuels, cannot yet be determined.

Past efforts in the utilization of liquid hydrogen as an aviation fuel include engine testing, which has established hydrogen's clear superiority to liquid hydrocarbons in virtually all aspects of engine operation, even without modifying existing engines, and extensive preliminary design studies of both subsonic and supersonic aircraft. Because of hydrogen's low density, these designs have tended to be very large—at least L-1011 or 747-size—in order to be cost competitive, but the current escalation in aviation fuel costs may tend to make smaller aircraft somewhat more interesting. Safety, incidentally is far less of a problem than most people think, although some public education to counteract the "Hindenburg syndrome" would undoubtedly be needed. Liquid hydrogen has seen extensive application in the space program with virtually no safety problems, and in wide commercial use could probably become just as safe as gasoline or present jet fuels. However, cost uncertainties, and especially the need for a nationwide manufacturing and distribution capability, will probably postpone the extensive implementation of hydrogen fuels until around the end of the century.

LIQUID METHANE

Liquid methane has also been examined as another alternative fuel, although not in as much depth as has liquid hydrogen. Liquefied natural gas—almost pure methane—is available today, but has not proved competitive with current aviation fuels even at the prevailing high prices. Methane could be considered for the future, but since its energy per unit mass is only slightly better than that of fossil-derived liquid hydrocarbons and its energy density is far worse—see table—it is not likely to be a serious contender.

In view of the above discussion on new fuels, we recommend to the committee that it support a careful and extensive assessment of both synthetic hydrocarbons and liquid hydrogen as future aviation fuels. Included in such an assessment, besides technical design and

operational factors, should be detailed projections of investment and operating costs, environmental impacts, utilization, overall effect on the Nation's economy, energy and materials needs, and interaction with other fuel-using segments of the economy. Manufacturing and distribution systems must, of course, be an essential element of the assessment.

Finally, although the limiting factors in the utilization of hydrogen as an aviation fuel are certainly those associated with the manufacturing and distribution systems rather than with the aircraft or engines, we suggest that the present modest NASA program in the pertinent aircraft technology be maintained; that is, the development of low-mass pressurized tankage and insulation, as well as other aerodynamic, structural, and systems problems associated with the high volume and low storage temperature of liquid hydrogen.

NUCLEAR PROPULSION

An extensive development program in aircraft nuclear propulsion (ANP), conducted by the U.S. Air Force and the Atomic Energy Commission, was terminated in 1961. Subsequent developments, however, particularly in aircraft size escalation and in the growing scarcity and cost of hydrocarbon fuels, have stimulated reconsideration of the concept at this time by both the Air Force and the AEC.

In the nuclear-powered aircraft, a fission reactor is used to heat a working fluid, which might be either a liquid metal—for example, potassium or sodium—an inert gas—for example, helium or noble-gas mixtures—or a molten salt. The hot fluid normally flows to a heat exchanger and transfers heat to a secondary fluid loop. The secondary fluid carries the heat to the engines, thereby eliminating the possibility for radioactive contamination of the engines. The secondary hot working fluid can either drive a turbine to power a fan or propeller or, more likely, deliver heat to a heat exchanger which replaces the combustion chamber in a standard engine. Most designs also include the capability for burning chemical fuels.

In the modern concept of this engine, the reactor and all radioactive components are totally contained within a fully crashproof "unit" containment vessel or shield, so that the radiation level in and around the aircraft is maintained at a harmlessly low level even at full reactor power. This feature, made possible solely by the use of aircraft large enough to carry the heavy shield, is what primarily distinguishes the modern nuclear airplane from the old ANP concept. More about "crashproofing" later.

The nuclear-propelled airplane has only one unique performance feature: essentially unlimited range—it can stay aloft almost indefinitely. When the pilot of a chemically-powered aircraft takes off, he knows that 6 or 7, or maybe even 20 hours later he has to land—not matter where—when he runs out of fuel. The pilot of a nuclear-powered plane knows he can always fly to another field, no matter how distant. Also, in sufficiently large aircraft, the nearly-constant mass of the nuclear powerplant system provides a substantial im-

provement in payload capability as compared with all-chemical-fueled aircraft, especially for long range trips.

The two principal barriers to the development of nuclear aircraft have been the lack of a truly important mission and concerns about public safety. With impending shortages and high costs of conventional fuels, however, a review of these "barriers" appears worthwhile.

Current nuclear aircraft concepts consider minimum payloads of 250 metric tons—550,000 pounds—as compared with about 100 metric tons for the C-5A. Many design studies have postulated even larger payloads. Some possible missions for such an airplane or seaplane, both military and civil, are included in this testimony as Appendix A. These missions are those which best utilize the large payloads and the near-infinite range offered by a nuclear propulsion powerplant.

The "safety barrier" represents perhaps the most severe problem faced by the nuclear aircraft. Before a nuclear aircraft can become operational, or even be flight tested, it must be demonstrated that under no circumstances can the public be endangered by any accident—even a full-scale crash—in which a nuclear plane is involved. Prior to termination of NASA's nuclear propulsion activities in January 1973, a program to develop the necessary safety technology had indicated—by rocket sled tests—that reactor containment designs could be capable of sustaining a Mach 1 impact into a concrete wall without leakage of their contents. Also, NASA had formulated theoretical containment designs which could sustain a full post-crash reactor meltdown without thermal failure. However, despite these promising beginnings, clear demonstration of reactor safety still has a long way to go, even if flights are restricted to over-water routes.

In the technology area, although considerable research and development is needed, there appear to be no major barriers to the achievement of subsonic flight. Nuclear-powered supersonic flight would require extensive new technical knowledge, but the use of supplementary chemical-fuel power, as was proposed in the old ANP program, would provide some supersonic capability to a basically subsonic nuclear aircraft, especially when some of the newer fuels are considered.

The nuclear-powered aircraft concept must, of course, be compared with chemically-fueled aircraft using hydrogen or synthetic hydrocarbons, since the time frame of interest for all these concepts is certainly near or perhaps beyond the end of the century. However, even before such comparison studies can be undertaken, it is necessary to conduct rather extensive systems analyses of various elements in the nuclear propulsion concept. For example, it has not yet been established whether the reactor working fluid should be a noble gas—or noble-gas mixture—or a liquid metal, a choice which dictates many basic design features of the entire power system. Also, there has been no consideration of plutonium fuel, although in the time frame of interest it is not likely that uranium 235 will still be available. Many possible choices for heat exchanger materials, engine op-

erating parameters, chemical-fuel integration, and other variables have not been evaluated.

We therefore recommend that the committee support a program of analytical systems studies—not a development program—of nuclear aircraft propulsion concepts. These studies should include airframe considerations, and, eventually, should be incorporated into the overall assessment of the type we recommended earlier for synthetic and hydrogen fuel utilization; that is, to determine whether nuclear energy is most effectively used for direct in-flight power, or indirectly for the manufacture of chemical fuels.

Mr. Chairman, I hope this testimony has been helpful in providing you with the information you need—additional detail may be found in the references listed in Appendix B. I am, of course, convinced that the continued growth of the aircraft industry is vital to the health of this Nation. My presentation has been primarily oriented to the future because I firmly believe that sustained active attention to the support of advanced technology is essential to the nurturing of that industry.

I thank you again for the opportunity to appear here today, and, with Mr. Simpson, stand ready to answer any questions you may have.

[Appendix A]

Possible Missions for Nuclear Aircraft (250 Metric-Ton Payload)

1. Military Missions

Transport by a relatively small fleet of a full Army division (or equivalent-mass payloads) to remote "brush-fire" areas on very short notice, with no need for first establishing massive logistic capability (e.g., fuel for return) in the target area. Current subsonic nuclear aircraft design concepts in the suggested payload range are capable of using existing (2500-meter) runways; seaplane designs are also possible.

Transport of large payloads in single-leg flight modes (i.e., with no need for intermediate supply bases), independent, except for added flight time of (1) the need to avoid overflights of sensitive territories, (2) the need to avoid enroute weather, or (3) target-area weather (the aircraft simply holds in a convenient pattern until the weather clears).

Transport of multiple payloads for parachute drop to a number of different areas in a single flight, with no need for return-fuel supply bases.

Transport of extremely large single-unit payloads (e.g., complete mobile nuclear powerplants) to remote locations with no need for logistic support.

Missile-launching platforms similar to nuclear submarines, but with much higher mobility and almost as undetectable by radar or satellite on short-term scales.

Long-term airborne reconnaissance, "search and destroy" (of submarines), anti-missile or anti-aircraft patrol, command-post operations, etc.

Long-range tug capability for smaller or special-purpose chemically-fueled aircraft. One interesting mission in this category is to utilize very large nuclear aircraft circling the world indefinitely. Chemically-fueled aircraft takeoff, hook on to the tug for a "free ride" (perhaps halfway around the world), and then drop off to land. Payload capability for long flights is thereby enormously enhanced, since virtually no cruise fuel is needed.

2. Civil Missions

Air Freight. The capability for weather avoidance, flight legs as long as necessary, and no logistic support in the delivery area offers enormous improvements in freight-carrying cost and flexibility. Sea-based aircraft may enhance these benefits. The high payload mass capability of large nuclear

aircraft over long ranges also offers pertinent economic advantages for bulk cargo on such missions.

Transporting large, special-purpose unit payloads either to remote (unsupplied) areas or over long distances; e.g., construction equipment, mobile powerplants, space shuttle orbiters, etc.

Transporting large numbers of passengers over long distances both economically and rapidly; e.g., an extension of the proposed Laker Airways Sky-train concept.

Airborne research platforms for earth resources studies, earthquake research, meteorological studies, oceanographic data-taking, and other NOAA and Department of Interior missions.

Luxury cruise airlines, using mission patterns similar to those of surface cruise ships, but touching many more ports during a specified time period.

[Appendix B]

References for Additional Background

Variable-Cycle Engine

1. Swan, Walter C., "Performance Problems Related to Installation of Future Engines in both Subsonic and Supersonic Transport Aircraft," (to be published in Astronautics & Aeronautics, February 1975).

Supersonic Combustion Ramjet Engine

1. Dugger, Gordon L., and Billig, Frederick S., "Supersonic Combustion Ramjet," AIAA Student Journal, December 1973, pp. 8–12.

New Fuels

1. Brewer, George D., "The Case for Hydrogen-Fueled Transport Aircraft," Astronautics & Aeronautics, Vol. 12, May 1974, pp. 40–51.
2. Escher, William J. D., "Future Availability of Liquid Hydrogen," Astronautics & Aeronautics, Vol. 12, May 1974, pp. 55–59.

Nuclear Aircraft Propulsion

1. Wild, John M., "Nuclear Propulsion for Aircraft," Astronautics & Aeronautics, March 1968, pp. 24–30.
2. Rom, Frank E., "Airbreathing Nuclear Propulsion—A New Look," NASA TM X–2425, December 1971 (also included in Nuclear News, Vol. 14, October 1971, pp. 79–84, 87).

Fuel Conservation

1. Grey, Jerry (Editor), "Aircraft Fuel Conservation: An AIAA View," June 30, 1974.

Senator Goldwater. Thank you very much, Dr. Grey. I have some questions that the Chairman wants me to ask and then I have a few of my own. Dr. Grey, NASA has a responsibility for the preservation of the United States as a leader in aeronautical and space science and technology and in the applications thereof to the conduct of peaceful activities within and outside the atmosphere. Do you feel that the program of advanced aeronautical and space technology of NASA meets that responsibility?

Dr. Grey. In general, yes, I do believe so, sir. There are certain limitations, however, in the overall funding of the NASA aeronautical and research and development program which we feel could be expanded upon.

For example, Dr. Fletcher noted in his testimony on July 16 that the variable cycle engine is really not receiving enough attention. We certainly could devote a great deal more money and effort to

this concept since it represents such a great broad-based potential for future capabilities.

We also believe, as I have indicated here in our testimony, that some expansion of the application of new fuels is essential because of the impending shortage of petroleum fuels. Also, consideration of a technology program in nuclear propulsion is warranted in the budget. But in general, the maintenance of necessarily strong support of aircraft technology is properly handled at the present time by NASA.

Senator GOLDWATER. Well, that is a problem that we on this committee and the Armed Services Committee are faced with constantly. It is not easy to convince other members of the Congress of the need for research and development, even of the need for maintaining our lead in airplanes. They have a rather warped idea on the subject of priorities. We feel that the maintenance of technological advancement, particularly in fuel, is an absolute must. So I would suggest that through your publications of your different associations you try to make available to the uninformed the kind of word they should be getting so that we will not have to give up almost when we know we should have research and development across the board and we have a hard time getting it.

Dr. GREY. Yes, sir, the AIAA does that in every avenue that we find it possible. We would be delighted to receive any suggestions that you or other members of the committee have in that regard.

Senator GOLDWATER. Just get the word out. You know the old saying, better to light a candle than complain about the darkness. We have got service clubs and women's clubs in this country that are just beating down the door for new speakers and you can reduce this to understandable language and maybe get them enthused.

Dr. GREY. We are in the process of doing that just as hard and fast as we can. Thank you very much for your words of support.

Senator GOLDWATER. Dr. Grey, do you think it would be possible for the aviation industry to go to liquid hydrocarbon or liquid methane fuel without other forms of transportation also going that route?

Dr. GREY. I assume you mean liquid hydrogen and liquid methane. We do not believe that would be feasible for some time to come. As I indicated, the basic problem in implementing liquid hydrogen is not the technology. It is the establishment of a countrywide logistic system for manufacturing, distributing, and handling it. If the aircraft industry were required to support the entire cost of both the development and implementation of that distribution system I do not believe it would be at all economical. We would need to have other segments of the economy also using either the hydroegn or methane.

Senator GOLDWATER. That question leads me into one that just came to my mind because I only heard about it yesterday. There is a company in Arizona, Anderson-Clayton, whose primary concern actually is cotton but they wrote me relative to a program they heard about that I believe the Army is involved in, making fuel from leftovers, manure, and so forth and so on. In fact, the man

who wrote me said some time in the rather immediate past was conducting an experiment using alcohol.

Have you done any work in that area?

Dr. GREY. There has been some work done. I believe that the use of mixtures of alcohol and hydrocargon, that is, conventional petroleum derived fuels, has proved to be quite effective in automative reciprocating engines. Up to as much as something like 15 or 20 percent ethyl alcohol in conventional gasolines does not introduce major changes in engine capability. The possible use of ethanol and methanol is being examined in other segments of the Government at this time.

Mr. SIMPSON. I think there are two fuels which can be made from any vegetable product, sewage, that could serve as fuel. They are methane and alcohol. If we once get methane or alcohol, it can be synthesized into most any kind of hydrocarbon fuel without a lot of trouble.

The basic problem with alcohol, and it is used conventionally in many automobile race cars, is its Btu content. Its Btu content is about 5,500 Btu per pound as compared to 18,400 for normal gasoline. So it would take three times as much of it.

Second, alcohol is hygroscopic and it picks up water out of the atmosphere, so we end up with a lot of water mixed in with the alcohol which produces nothing. But certainly, alcohol as an intermediate product or a prime source of fuel is quite practical and could be done. Its penalty in an automobile or truck or some such thing as this would be much less than it would be in an aircraft because it does not cost as much to haul the extra weight around.

Senator GOLDWATER. It would not require any changes in carburetion, would it?

Mr. SIMPSON. Yes, sir. You would have to put in different jets, but no basic change. I mean, bigger lines and a larger orifice in the carburetion system.

Senator GOLDWATER. Well, we have General Cooksey with us from the Army. Maybe he could drop a word on what they have been doing.

Dr. Grey, I understand the Air Force is looking at potential applications for nuclear aircraft propulsion but they believe that higher temperature capability might be needed. Yet, you state that current technology is adequate for nuclear aircraft. Could you comment on that?

Dr. GREY. Yes, sir. I think this is a very important point. It is one of the basic reasons that the previous ANP program ran into such difficulty. That is, in general the tendency is to identify the best possible performance that one might be able to predict and try to develop hardware to meet that performance.

For example, it would be very nice to run nuclear airplane engines at temperatures in the 1,600° or 1,700° (F) range, but it has been fairly well demonstrated that we can run a very respectable nuclear airplane in the 1,300° or 1,400° range, which is within the capability of current technology. It would not be as good an airplane, but it would be developed a lot faster and with a lot less effort than if we try to advance our goals too rapidly in a new technology.

What I am suggesting here is that even in an advanced field like nuclear propulsion, small steps can be sometimes more effective than trying to make giant steps. In effect, today's technology, that is, reactors which would generate air temperatures in the 1,200° to 1,400° (F)range, would be perfectly acceptable for powering subsonic airplanes of good size.

Senator GOLDWATER. Of course, if you can improve on our knowledge of metal you can get into those higher temperatures?

Dr. GREY. Oh, yes. There is no question that ultimately high temperature development is always an improvement. We are doing the same thing in our conventionally-fueled turbojets today. As we go to higher temperatures the performance goes up, but if we try to go to higher temperature engines too early in the game, or as a primary goal, we might postpone indefinitely the development of a viable, safe, and economically useful engine.

Senator GOLDWATER. What would you envision as a possible schedule for the development of a nuclear aircraft and what size aircraft would this be and again, what is your guess as to the cost to develop?

Dr. GREY. These are questions whose answers I can only offer as guesses, since there is, as you know, no current program in nuclear propulsion of aircraft.

During the next decade, I see nothing more than a technology program. I think the implementation of a development effort any sooner than perhaps 8 to 10 years from now might tend to prejudice the ultimate development of a viable nuclear airplane. The safety questions have to be answered very extensively by elaborate ground testing, including exhaustive subsystem and component evaluation, long before an engine configuration is established. Thus, since we should not even begin the development program until well into the next decade, it would be very close to the end of the century before we would flight test a nuclear airplane. Costwise, I would foresee something of the same magnitude of the ANP program: That is, on the order of $1 billion over perhaps a 20- or 25-year period. The cost of the initial technology program, however, shouldn't amount to more than a few million dollars a year.

Senator GOLDWATER. From your colleagues around the world do you have much information as to the activity of the other countries in this nuclear field?

Dr. GREY. To my knowledge, there are no active programs anywhere in the world on nuclear propelled aircraft. People are drawing pictures and doing preliminary designs of large airplanes and there are even some program projections for development of nuclear aircraft, but to my knowledge, there is no real systems analysis or experimental work being conducted.

Senator GOLDWATER. Thank you very much. Dr. Grey and Mr. Simpson. It has been a pleasure having you here. It has been a very interesting presentation and you lived up to your reputation.

Dr. GREY. Thank you very much.

Senator GOLDWATER. Our next witness will be Mr. Oscar Bakke, formerly Associate Administrator for Aviation Safety, FAA, who will discuss the impact of market factors on advanced aeronautical technology systems.

[The biography of Mr. Bakke follows:]

BIOGRAPHY OF OSCAR BAKKE, FORMER ASSOCIATE ADMINISTRATOR FOR AVIATION SAFETY, FAA

Mr. Oscar Bakke is a veteran of 27 years with the FAA and the Civil Aeronautics Board. On January 6, 1974 Mr. Bakke was appointed Associate Administrator for Aviation Safety in the FAA. In this position he was responsible for aviation safety procedures, aircraft airworthiness, airmen training and certification (including medical certification), airport safety and security, flight inspection of navigation aids, and safety rulemaking. Mr. Bakke retired on June 28, 1974.

Prior to his last position in FAA, Mr. Bakke was in charge of FAA's European, African and Middle East region, headquartered in Brussels, Belgium. Mr. Bakke was appointed to the Brussels post in 1971 and was responsible for the FAA programs in Europe, Africa and the Middle East including the certification of foreign aircraft intended for sale in the United States (such as the Concorde. Airbus, Mercure. Falcon, VFW 614, Corvette, etc.), the flight calibration of U.S. radars and navigation aids installed abroad, the regulation of U.S. air carriers and private operators outside the United States, the promotion of U.S. technology and the gathering of aviation intelligence.

Prior to his overseas assignment, he was the Federal Aviation Administration's first Associate Administrator for Plans heading a group within FAA assigned to develop a blueprint for a comprehensive program to enable the agency to meet the projected demands of aviation growth for the following decade and beyond.

In August 1961 he was named Director of the FAA's Eastern Region in which capacity he was responsible for the agency's operating programs in 15 northeastern states. His appointment as Regional Director followed the announcement of an agency decentralization plan which broadened the executive authority of regional directors and improved general FAA management. Bakke was selected to develop a prototype decentralization program in the Eastern Region which subsequently was adopted as a model for other regions.

A veteran pilot with experience both in the military and civil aviation. Bakke joined FAA in February 1960 as Director of the agency's Bureau of Flight Standards. Before joining the FAA, Bakke served 14 years with the Civil Aeronautics Board. He was Director of the CAB's Bureau of Safety from 1956 to 1960.

During Bakke's 27 years of professional experience in aviation, he served many times as representative and chairman of U.S. delegations to the International Civil Aviation Organization (ICAO).

Formerly a command pilot in the Air Force Reserve, Bakke is author of several Air Force manuals and publications on instrument flying and radio navigation. He is currently a Technical Adviser to the Radio Technical Commission for Aeronautics and is a former Director at Large of the American Institute of Aeronautics and Astronautics.

Born in Bergen, Norway, Bakke attended Brooklyn Technical High School and Wagner College on Staten Island, where he received his B.A. degree in 1941. Later, while attending Brooklyn Law School, he was called to active duty with the Army Air Corps. He was discharged as a major in 1946 after serving as a pilot instructor in the Training Command and as an air navigation specialist on the Air Corps Instrument Flying Standardization Board.

Bakke is married to the former Astrid Josephsen. Mr. and Mrs. Bakke are the parents of four sons.

STATEMENT OF OSCAR BAKKE, FORMERLY ASSOCIATE ADMINISTRATOR FOR AVIATION SAFETY, FAA

Senator GOLDWATER. You may proceed with your prepared text or we will make it part of the record and you can go any way you want.

Mr. BAKKE. All right, sir. I regret I have no prepared text to submit to the committee but I think I can review my concerns to the committee briefly and perhaps place some suggestions before you.

I note, Mr. Chairman, at least two remarks among the previous testimony and your questions concerning the testimony which has been submitted which I thought were rather relevant to the views that I would like to propound. One was your reference to warped priorities within the Congress and the other had to do with Dr. Grey's references to the need for small steps. As a matter of fact, these go to the heart of the principles that I would like to suggest to the committee, the first being that we have to a very considerable extent compromised the effectiveness of our technology development programs within the United States by reason of the fact that we have failed to take the governmental actions necessary to insure access to aeronautical markets and, by reason of that fact, much essential development, particularly with respect to aircraft development, has not taken place.

Second, we have been altogether too mesmerized with the need for comprehensive systems developments. In the light of the Apollo program it has appeared demeaning to take small incremental steps in technology improvement. I agree totally with Dr. Grey that we should reconsider some of our technology development programs in this light.

I believe that it is the responsibility of this committee to insure not only that specific ad hoc technology development projects are undertaken in the United States but that there also exists a system which insures that the total capability of the United States, including the private sector, is directed toward technology development and not be confined to Government-sponsored programs. The national policy which is to be adopted, in which this committee will doubtless have a very important role in the priorities to be established, must be considered in the light of how such policies may impinge on the role of transportation and the access to transportation markets. Accordingly, I would suggest that a few thoughts are necessary as a backdrop to the further consideration of this committee.

We have had opportunity to review in the recent past the possible contribution of aviation to the increased efficiencies of our urban centers. We have been examining the role of transportation in achieving higher orders of efficiencies in our major cities. We have played with the thought that, if aviation could gain access to our city centers, there is another order of contribution that could be made in the increase of the commercial and industrial efficiency of those cities. Several efforts have been made but I would like to refer to just a couple of them as illustrative of the problem we have encountered.

At the foot of the World Trade Center in New York there lies a strip of new real estate which was created by the Port of New York Authority by landfill which represents approximately 100 acres of property, a strip about 900 feet wide, almost 2,000 feet in length.

In anticipation of the availability of this strip, we sought its use at least on a temporary basis for STOL access to the financial district of Manhattan. I know that time does not permit a detailed exploration of its advantages and disadvantages but I would like merely to summarize and would be happy to add to the record further if the committee so desires.

Particularly among the operators of small less sophisticated aircraft, there was unanimous support for the use of this strip on a temporary basis by existing aircraft on a nonsubsidy basis, the use of which could begin immediately.

All of the operators who were consulted during this examination were of the view that immediately upon the beginning of such operation, the air carriers concerned would be caught up in the normal cost escalation process and would need relief through what has throughout the history of aviation been a normal incremental development of productivity. They would look for the next generation of aircraft. The first operation would have involved something like the Twin Otter, dash 300 series. It would have been a 19-passenger aircraft. Within 3 years they suggested it would be necessary to consider an aircraft possibly double that size. Perhaps within the next 7 years an aircraft double that size again. So that over the next 15 years there would be perhaps four or five developmental increments which would bring us ultimately to the optimum sized aircraft for that market. Were such incremental development possible, the carriers were confident that such operation could be conducted without the need for Federal subsidy.

The fact is, however, the decision was made not to allow the use of this property for that purpose. That property has now lain vacant except for the storage of construction materials and building equipment, for the last 4 or 5 years. It could have been used for a far more essential purpose. The decision, however, not to permit its use for such purposes was largely political. Aviation within the city represented a high political risk program. There were too many antitechnologists, too many environmentalists and others, without adequate cause I should say, who were in opposition to the program. There was also a bit of deal-making which stipulated that there should be no major urban development which does not include a substantial portion of that development as low cost housing. In other words, it is in effect an effort to preserve a kind of political status quo by containment of a welfare constituency.

In 1967 we persuaded the city of New York to publish a request for proposals for an economic and engineering feasibility study of a huge multifunctional structure to be built on Manhattan Island over the present dilapidated piers centered approximately at 34th Street. This undertaking was to integrate steel wheeled, rubber tired, water borne and air vehicle (VTOL and STOL) terminal facilities within the structure and to exploit this tremendous concentration of transportation by including more than 15 million square feet of salable commercial and industrial space. Although nine excellent proposals were submitted in response to the RFP, and although the Federal Government offered to fund half the cost of the studies, the mayor decided to abandon the investigation when communities in the vicinity of the site protested the impact such a development would have upon existing patterns of land use.

When you spoke of inverted priorities, Mr. Chairman, I recalled particularly as a result of visits last week to the city of Newark, the self-defeating impact of programs that have been purely socially

motivated, that have sought to restructure our major cities to achieve social objectives only—housing, education, health care, cultural purposes have been sought. Anyone who has the opportunity to visit some of the projects in the city of Newark that have been accomplished within the last decade, I think will agree that they have miserably failed to accomplish their purpose. We have neglected to focus on the proposition that a city needs economic reason for existence and that, unless that reason for existence continues, the possibility of generating and distributing wealth, of creating jobs and of making meaningful participation in the economic life of the Nation will not be permitted to its occupants. Obviously, transportation has a vital role to play in insuring the economic efficiency of the city. And the final step of the process is that, were transportation given an opportunity to participate in insuring the continued efficiency of the city, the possibilities of an incremental development of aircraft technology by the private sector would have been enhanced.

Several aircraft manufacturers had given us assurance during the mid-sixties that, were access to the city of New York guaranteed, they would begin immediately the development of a prototype VSTOL aircraft for such service. In a couple of cases we had assurances that production of such an aircraft would be initiated immediately upon access to a major urban market. However, although we have attempted such access in at least a dozen cities of the United States, we have met with little success, not for lack of economic justification or because of technological deficiencies but simply because governmental decision making and action were not forthcoming.

There is an ironic twist to this fact because, as you will recall, Mr. Chairman, the basic strategy which underlay the development of the Airport Airways Development Act of 1970 was to create a fund of money to be available at the Federal level and a system of distribution which would in effect increase the bargaining power of the Federal negotiators for the development of air transportation systems. While there may very well be great merit in the objectives of special revenue-sharing in other programs, it is especially inappropriate to air commerce.

I would suggest to you that the most important single force which shapes transportation systems in the United States is the control of land use. The control of land use in the United States is typically exercised by our smallest political jurisdictions. The smallest political jurisdictions are typically motivated primarily by the preservation or the extension of the community. Anything which constitutes a threat to the community, will as a matter of natural course be rejected by local government, however great the regional or national needs may be. Accordingly, some kind of balance to insure that the regional and national requirements for transportation are met is essential.

The Airport Airways Development Act was intended to provide a better balance. The seeking of that balance, Mr. Chairman, has not been one of the principal objectives in the use of the new Federal powers under the Airport Airways Development Act.

I would suggest to you that this committee might very well consider that development of new aviation technology is of and by itself

a fruitless effort unless provision is made in government to insure that that new technology does in fact result in access to essential markets. And in the process of doing that, I would suggest to you as well that a far more effective solution can be developed for the ills of our major metropolitan areas. There are numerous persons and organizations outside Government who are capable of making significant contributions to aviation technology development—it is by no means primarily a governmental mission. The opening of transportation market is a completely different situation, however it can only be accomplished through governmental action. Unless Government is prepared to carry out its responsibilities in land use control and other related jurisdictional areas, no amount of technology development will suffice.

That in general, Mr. Chairman, is the thesis that I would like to lay before you. Now or at some other convenient opportunity, I would be delighted to pursue it further should the committee find it of interest.

Senator GOLDWATER. I want to thank you very much for that very interesting approach. This is a major problem for those of us in the Congress who realize the importance of research and development. We are divided in this Congress. We have those who feel that Federal money creates jobs. It does not. The only progress we make in this country is when the Government works hand in hand with industry and the academics to create new tools and new items. This may sound strange coming from one who is supposed to be a bad old conservative, but I realize that the time has long been with us when real research and development cannot be engaged in by the private sector alone.

I am thinking, for example, of the SST, and had Boeing undertaken to do that, I think it would have required four times its corporate worth. So the Federal Government has to, I think, assume more and more of the role on a pay-back basis. If we can do that, we will get the research and development going.

I am afraid we have lagged. We are trying to cut the military R. & D. every year. I do not think that is wise. We are not developing new items as fast as I would like to see them developed, although I suppose we can say we lead the world in technological developments, electronic developments, and so forth.

So I appreciate very much what you have said. We have no questions to ask you because we did not have a prepared text and that is the only way we can sneak up on you.

Anything you would like to enlarge on, add anything to it, you can send your papers in at any time. I want to thank you for being with us.

Mr. BAKKE. Thank you very much, sir.

Senator GOLDWATER. Our next witness will be Maj. Gen. Howard Cooksey, Deputy Chief of Staff for Research, Development and Acquisition, U.S. Army, and with him will be Paul Yaggy, Director of Research, Development and Engineering, U.S. Army Aviation Systems Command.

[The biographies of General Cooksey and Mr. Yaggy follow:]

BIOGRAPHY OF MAJ. GEN. HOWARD H. COOKSEY, USA

Howard H. Cooksey was born in Brentsville, Virginia, on 21 June 1921, graduated from Manassas High School, Manassas, Virginia, in June 1939 and from Virginia Polytechnic Institute, Blacksburg, Virginia in 1943.

He began his military career when he graduated from Officers Candidate School, Fort Benning, Georgia, in July 1943 and later attended the Armor School at Fort Knox, Kentucky.

His service includes a tour with the 158th Regimental Combat Team during the Northern Philippines and Luzon campaigns in World War II; here he was awarded the Bronze Star, Combat Infantry Man's Badge and the Purple Heart.

During the Korean War, he served with the 7th Infantry (Hour Glass) Division, earning two Oak Leaf Clusters to the Bronze Star and a second award of the Combat Infantry Man's Badge.

He served as Deputy Commander, 2d Battle Group, 6th Infantry Regiment, in Berlin, in 1961-1962, and later commanded the First Brigade, 2d Infantry Division, in Korea, in 1966-1967.

Returning from the war in 1945, he held a number of administrative and command positions before being assigned as Assistant Professor, Military Science and Tactics at Drexel Institute, Philadelphia, Pennsylvania, in 1949-1951.

From 1954 to 1958, he was assigned as a staff officer with the Office, Chief of Research and Development, in Washington, D.C., before attending the Armed Forces Staff College in 1958.

From 1959 to 1961, he served with Headquarters, United States European Command, in the Joint Secretariat.

He attended the National War College in Washington, D.C., in 1962-1963 and following graduation became Deputy Chief, Combat Materiel Division, Office Chief of Research and Development, Department of the Army. In February 1965, he became Chief of the Combat Materiel Division, and later in 1965 he was assigned as Executive to the Chief of Research and Development prior to being assigned as Commander, 1st Brigade, 2d Infantry Division in Korea.

From September 1967 to May 1968, he served as Director of Personnel (J1), US Strike Command, MacDill Air Force Base, Florida.

In June 1968, General Cooksey was assigned as Assistant Division Commander, 23d Infantry Division (Americal), Vietnam, a position which he held until May 1969, when he became Deputy Chief of Staff, Plans and Operations, US Army, Vietnam. In April 1969, he was awarded the Silver Star, and prior to his departure from Vietnam he received the Distinguished Service Medal.

He returned to CONUS in December 1969 and on 10 January 1970 assumed command of the US Army Training Center, Infantry, and Fort Dix, Fort Dix, New Jersey. He held this position until 5 May 1972 when he returned to Da Nang, Vietnam, to assume command of the First Regional Assistance Command, United States Military Assistance Command, Vietnam, on 30 May 1972.

General Cooksey departed his headquarters in Da Nang on 25 January 1973 to assume additional duties as Acting Chief of Staff, United States Military Assistance Command, Vietnam, during the period following the signing of the Vietnam Cease-Fire Accords. On 28 March 1973, he moved to Nakhon Phanom, Thailand, and became the Deputy Commander, United States Support Activities Group/7th Air Force.

General Cooksey was assigned as Deputy Chief of Research and Development, Department of the Army, on 2 November 1973. He is presently serving as Acting Chief of Research, Development and Acquisition.

BIOGRAPHY OF PAUL F. YAGGY, U.S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY, MOFFETT FIELD, CALIF.

Paul Francis Yaggy was born in Detroit, Michigan, on 4 August 1923. His high school years were spent at Vermilion High School, Vermilion, Ohio, and at Dover High School in Dover, New Jersey, where he was graduated in

1941. He received his college education at Taylor University, Upland, Indiana, the University of Notre Dame, South Bend, Indiana, and San Jose State College, San Jose, California, where he was graduated with distinction (honors in engineering) with a BSEE. Mr. Yaggy has pursued graduate study at Stanford University, Stanford, California, since 1967.

From 1943-1946, Mr. Yaggy was on active duty with the U.S. Navy. Following an intensive college training program in aeronautical engineering from which he was graduated in 1944, he was assigned as an Aircraft Maintenance Officer, serving one year in a special detachment at the Ames Aeronautical Laboratory of the National Advisory Committee for Aeronautics at Moffett Field, California, doing wind tunnel research on various World War II aircraft at high subsonic speeds. He was released to inactive duty in the fall of 1946.

From October 1946 to July 1951, he held a succession of engineering positions as a civilian employee of the National Advisory Committee for Aeronautics at Moffett Field, California.

Recalled to active duty with the U.S. Navy during the Korean conflict in 1951, Mr. Yaggy supervised the maintenance of a squadron of ASW aircraft in addition to serving as chairman of all aircraft accident boards for the squadron.

Following his return to civilian status in November 1952, he returned to the NACA at Moffett Field, California, as a research scientist. He has attained local and national recognition in the specific phases of V/STOL aircraft related to rotors, propellers, and ducted fans, and has served as a consultant to industry, the Armed Forces, and other NACA Centers. With the redesignation of the NACA to Ames Research Center, National Aeronautics and Space Administration, Mr. Yaggy's increased responsibilities included research on recovery systems for spacecraft and lifting body reentry vehicles. In 1965 he was appointed Technical Director of the U.S. Army Aeronautical Research Laboratory at Ames. He served in this capacity from the date of its establishment until his assignment in 1970 as Director of the Army Air Mobility Research and Development Laboratory complex established that year.

Mr. Yaggy is an Associate Fellow of the American Institute of Aeronautics and Astronautics. He has served on Technical Committees of the Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Helicopter Society. He serves on the Board of Directors of the American Helicopter Society as a Director-at-Large, and received the Society's 1972 Dr. Alexander Klemin Award presented for "notable achievement in the advancement of rotary-wing aeronautics". Mr. Yaggy is currently Deputy Chairman of the Fluid Dynamics Panel of the Advisory Group for Aerospace Research and Development of the North Atlantic Treaty Organization, having served on this Panel in various capacities in recent years. He has served on the NASA Advisory Subcommittee for Aircraft Aerodynamics. He is the author, or co-author, of numerous published technical papers. As an Assistant Professor at San Jose State College, Mr. Yaggy has also taught engineering courses. He has been a guest lecturer at the von Karman Institute in Brussels, Belgium, the Royal Aeronautical Society in London, England, and at Stanford University in Stanford, California.

STATEMENT OF MAJ. GEN. HOWARD H. COOKSEY, ACTING CHIEF OF RESEARCH, DEVELOPMENT, AND ACQUISITION, U.S. ARMY, ACCOMPANIED BY PAUL F. YAGGY, DIRECTOR OF RESEARCH, DEVELOPMENT, AND ENGINEERING, U.S. ARMY AVIATION SYSTEMS COMMAND

Senator GOLDWATER. General, you may proceed as you desire. We can make your formal presentation a part of the record and you can take off any way you want.

General COOKSEY. Thank you very much, Mr. Chairman.

We have, as you know, submitted material for the record. We would like to talk about that shortly, not cover the entire thing.

We feel we do have a very dynamic technology program. We have selected three flight concepts and one propulsion concept which we feel are representative of our program and we would like to discuss those with you.

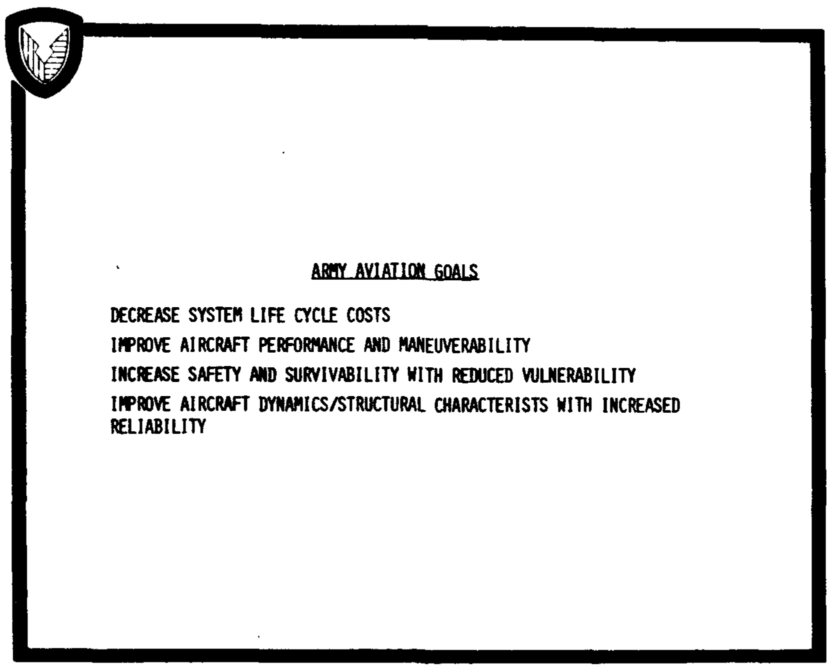
Mr. Paul Yaggy, as you have said, is the director of our research, development, and engineering laboratories at the Aviation Systems Command. He will make our presentation. Mr. Yaggy.

Mr. YAGGY. Senator, with your permission, I would like to make my presentation standing, addressing the vugraphs.

Senator GOLDWATER. Go right ahead. We can turn the lights down.

Mr. YAGGY. Senator, as I am sure you are aware, in the past decade the Army has found a significantly increased use for aircraft and particularly those which provide VTOL capability. This capability, in our interpretation, is manifested primarily in the rotary wing type aircraft. We have pursued these areas of technology, in advance of requirements which we envision in the future because we have found ourselves in excess of the state of the art of the technology which we have available to us. We have attempted to demonstrate our foresight in that regard because we realize that there is no justification for us to enter knowledgeably into production of the technology which has not had significant reduction in risk. Therefore, our goals are set in that fashion.

This next slide (fig. 1) indicates the goals that we have selected. First, we look at the matter of cost. This may sound rather strange for a technologist but it is extremely important to us that



Page 183 Line 19

FIGURE 1

we do stay within limits which we can afford. That means not just the acquisition cost but the life cycle cost as well. We attempt to provide, then, improved aircraft performance and maneuverability which is so important to our mission because so much of it is in the nap of the earth and at low level.

In addition to that, because of these types of operations, we also have the need for safety and survivability and reduction in vulnerability, but all of these potentials would be of very little worth if it were not that we had an aircraft which has dynamic and structural characteristics commensurate with increased reliability. So our time is limited.

We have chosen to show these four areas. We pursue these both in-house and by contracts, by international and national efforts. We pursue it jointly with our sister services, the Air Force and Navy, and through our unique arrangements for joint participation with NASA.

We use, of course, the customary facilities such as wind tunnels, flight simulators and computational analysis which are characteristic of our area.

The scope of my presentation is indicated on this slide (fig. 2). We will deal with these four which General Cooksey has already mentioned, three of them are demonstrators and one is an engine program. These will give you the spirit and character of our efforts. Obviously, the program is much too broad to encompass in any other manner of presentation.

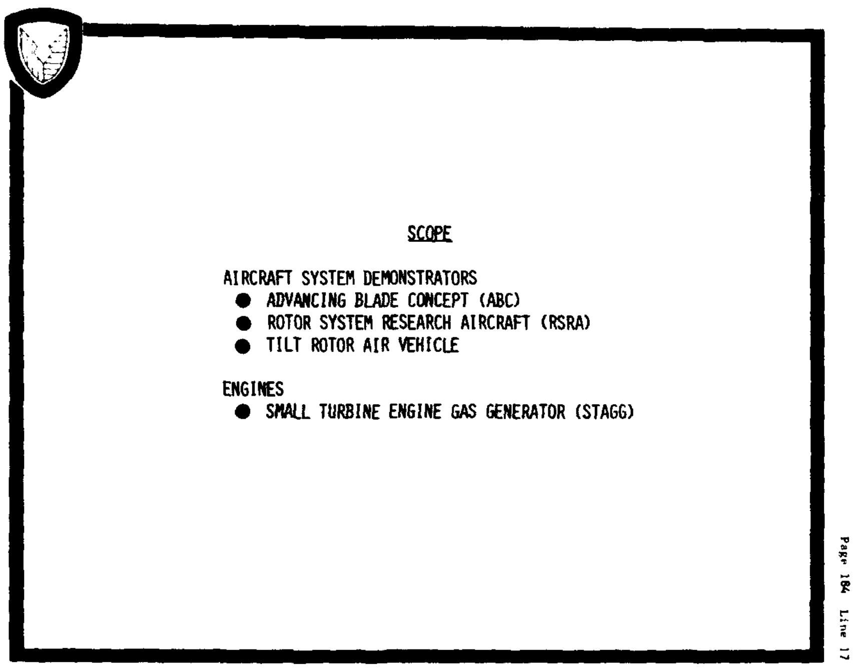


FIGURE 2

38-266 O - 74 - 11

First, I would like to address the concept known as the Advancing Blades Concept (fig. 3). This concept is one which uses a counter-

FIGURE 3

rotating hingeless rotor such as you see here. It is constructed with a titanium spar blade which has a fiberglass cover and along with the other characteristics of this vehicle tends to reduce its vulnerability and increase its survivability, providing additional safety. The tail rotor characteristically found on conventional helicopters is eliminated. This is accomplished by controlling, differentially, the rotors to give directional control.

Most unique about this vehicle is its capability for providing lift, and that I will discuss in just a moment.

The next slide (fig. 4, p. 157) indicates some of the characteristics and objectives of this program: increased safety through the elimination of the tail rotor and reduced acquisition and maintenance costs. We are interested in the ABC's high speed potential capability.

Senator GOLDWATER. Is Sikorsky building this for you?

Mr. YAGGY. Yes, sir.

Senator GOLDWATER. I saw this model out there last year.

Mr. YAGGY. All right, sir, since you are somewhat familiar, I will shorten my presentation.

Senator GOLDWATER. Do not do that.

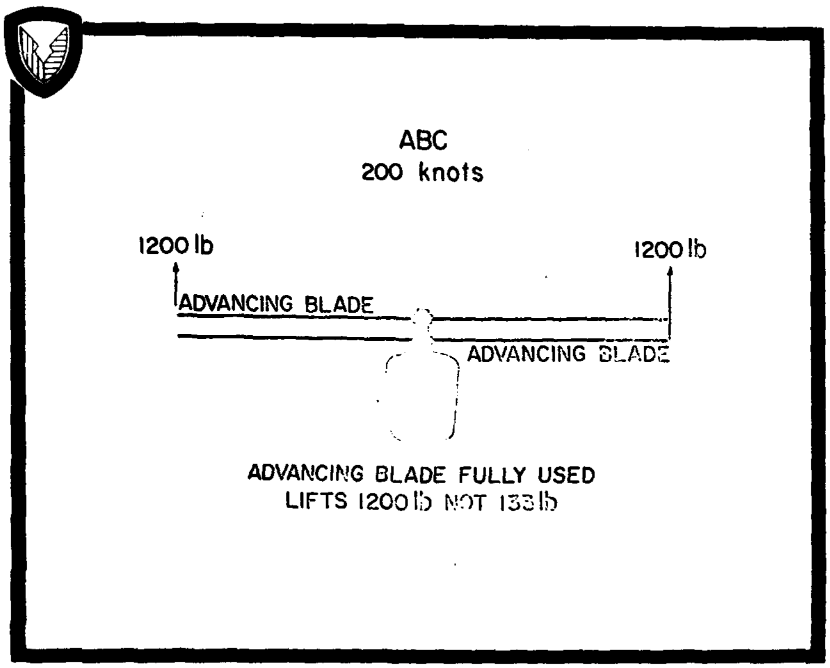
Mr. YAGGY. We do have high speed capability in this vehicle up to 300 knots which is a capability not inherent in rotor systems in general. We have reduced maintenance, as I mentioned, but more than that we provide good maneuverability. This maneuverability comes from the rotor system I will describe in a moment, and also

ABC POTENTIAL
ADVANTAGES

- TAIL ROTOR ELIMINATED
- HIGH SPEED CAPABILITY WITH AUXILIARY THRUST (300 knots)
- REDUCED MAINTENANCE
- GOOD MANEUVERABILITY
- SMALL ROTOR DIAMETER

Page 185 Line 9

FIGURE 4



Page 186 Line 6

FIGURE 5

we have a smaller rotor diameter because of the counter-rotating characteristics and by removing the tail rotor we are able to get into smaller areas, which is very important in the Army's missions.

The next slide (fig. 5, p. 157) indicates the significant characteristics of this vehicle. Customarily, in a single rotor vehicle, the retreating blades, that is this blade which is moving away from the oncoming airstream, suffers stalling and consequently cannot carry its share of the lift. Therefore, in order to maintain balance on the vehicle the advancing blade must also reduce its lift carrying capability and at 200 knots, as noted at the bottom of the slide, a conventional helicopter can only carry 133 pounds on each of the rotor systems compared with 1,200 pounds for the ABC. Therefore, in order to get the high speed from compounding rather than putting a lifting surface on this vehicle it is possible for us to simply compound for thrust and carry the lift continuously on the rotor itself. Because of the ability of the rotor itself to carry offset loads, with each stage cancelling the other, we are able to maintain significant lift during maneuver, thus increasing agility and controllability, whether in hover——

Senator GOLDWATER. Those are counter-rotating?

Mr. YAGGY. Yes, sir. I will set it right here so you can see it.

Senator GOLDWATER. In the maneuvering, does the rudder act as efficiently as the tail rotor would operate in a turn?

Mr. YAGGY. Sir, at higher speed flights, the tail surfaces become as effective as they would in the fixed wing aircraft. In hover mode we get the same type of control as we do in ordinary helicopter applications, except we get the differential control of the two stages so there is a resulting torque applied to the vehicle because of the torque that is applied on each stage.

Senator GOLDWATER. That comes from the rudder pedals?

Mr. YAGGY. Yes, sir. Interconnected and phased out depending on the cruise speed.

Senator GOLDWATER. And the control of the aircraft would be the same as on a conventional helicopter.

Mr. YAGGY. Yes, sir. The pilot is not aware that he had anything different than he had before.

Senator GOLDWATER. Would the rigid rotor concept work?

Mr. YAGGY. Sure. This is a rigid rotor. It is hingeless. It has no flapping hinges and no lag hinges. It is a very stiff rotor. Consequently, that reduces the vulnerability; increases survivability. As I indicated that is combining structural techniques with the——

Senator GOLDWATER. I understand the rigid rotor is the most efficient rotor system but it does have a weakness in lateral movements, quick lateral movements. Do you have that in this aircraft?

Mr. YAGGY. No, sir, we do not because of the control systems which have been applied to it. We have had this aircraft only 4½ hours in flight and I might mention to you that we did encounter a control problem which could not have been foreseen. The first of these aircraft did suffer damages. Consequently, we have gone back and looked now at the problems associated with it to a greater degree, including advanced wind tunnel tests, which have been of benefit not only to this effort but to our entire rotor technology program. We now have resolved the problem and are about ready to go into flight tests with the second vehicle. I would point out that this indi-

cates the viability of such a demonstrator as this. Had it been encumbered with all the sophisticated weaponry and avionic systems, et cetera, in the pre-production program, the loss could have been drastic.

Senator GOLDWATER. What was the nature of the problem?

Mr. YAGGY. The vehicle pitched up and settled into the ground.

Senator GOLDWATER. Pitched up from——

Mr. YAGGY. It was in 30 knot flight.

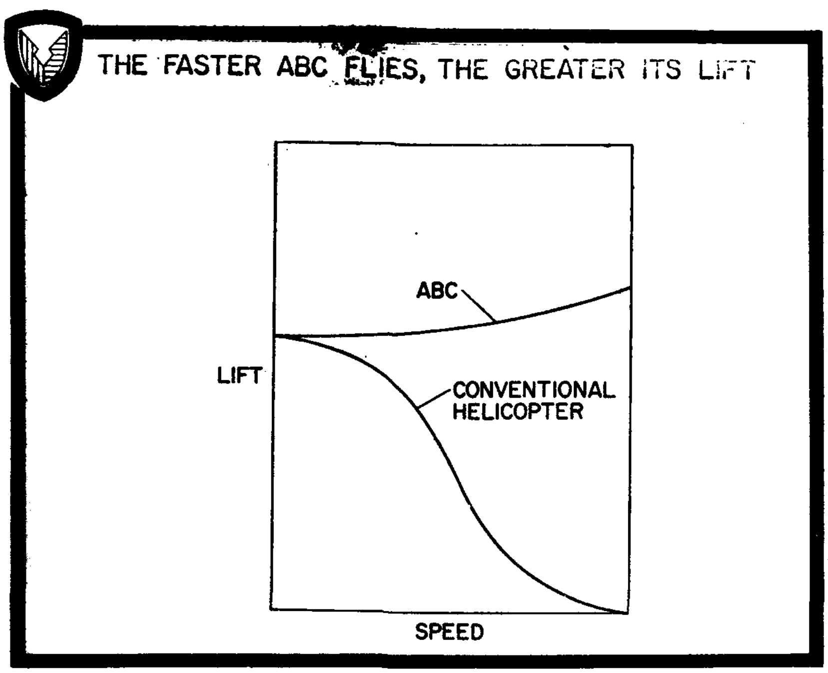
Senator GOLDWATER. What causes that?

Mr. YAGGY. It is a peculiar interaction of the two rotors and the downwash from one impinging on the other, but it is a characteristic that is inherent in single stage rotors as well, and this investigation has given us a new insight into how to correct that and provide greater capability in our single rotor aircraft as well.

Senator GOLDWATER. I asked them about that last year and they did not see any problems. I remember the contra-props that we tried near the end of World War II would not have a similar effect but did have a problem related to that.

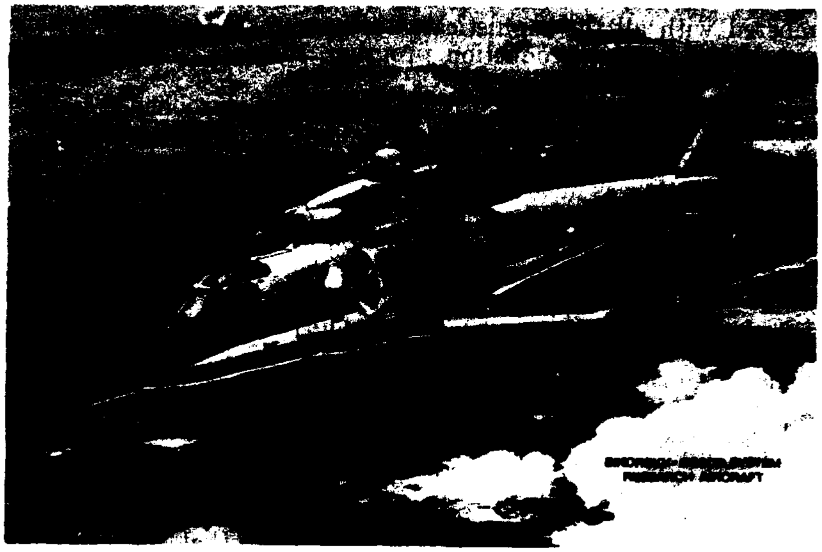
Mr. YAGGY. Yes, sir. This program was documented and had perhaps more wind tunnel investigation prior to its fabrication than any other program we have done. Despite that fact, and it is characteristic of rotary wing problems, the situation which occurred could not have been anticipated. Essentially, in rotary wing research and development we have completely exhausted the empirical approach used in the past and now we must have sophisticated information to carry on the effort.

This slide (fig. 6) indicates the increased capability in speed and lift which generates from the ABC concept.



Page 169 Line 21

FIGURE 6



Page 189 Line 23

FIGURE 7

Next slide (fig. 7). The next system which I would like to address is known as the rotor systems research aircraft. This is a joint program that we have with the NASA under our joint participating agreement. It has resulted from an early joint participating agreement. It has resulted from independent studies since the early 1950's in the areas in which we have been looking for methods

ROTOR SYSTEMS RESEARCH AIRCRAFT PROJECT

OBJECTIVE

DEVELOP A GOVERNMENT FLIGHT RESEARCH VEHICLE WITH SUFFICIENT VERSATILITY TO PROVIDE FOR ECONOMICAL AND TIMELY;

IN-FLIGHT VERIFICATION OF ROTORCRAFT METHODOLOGY AND SUPPORTING TECHNOLOGY

RESEARCH ON PROMISING NEW ROTOR CONCEPTS

Page 190 Line 7

FIGURE 8

for demonstrating in flight the capabilities of rotor systems. And in order to do this, we have to provide a testbed which has an advanced capability beyond that which is available today.

The next slide (fig. 8, p. 160) gives the objectives of the program which are to come up with something we can use economically and timely not only to verify methodology but with the ability to test several rotor systems on it.

The next slide (fig. 9) indicates some of the characteristics of the

RSRA

CONCEPT

ESCAPE SYSTEM	PILOT/CREW SAFETY
WING AND AUXILIARY PROPULSION	INCREASED ROTOR SIZE TEST CAPABILITY SIMULATION CAPABILITY SAFETY OF ROTOR LOADS BUILDUP TESTS OF UNLOADED ROTOR CONCEPTS
ELECTRO/MECHANICAL COMPUTER CONTROLS	ADAPTABILITY TO VARIOUS ROTOR REQUIREMENTS ADVANCED CONTROL SYSTEM STUDIES
ROTOR, WING, AND AUXILIARY THRUST INSTRUMENTATION	HIGH QUALITY QUANTITATIVE DATA THEORY-MEASUREMENT CORRELATION
VIBRATION ATTENUATION	ADAPTABILITY FOR BROAD RANGE OF TEST ROTORS

Page 190 Line 11

FIGURE 9

production components used to reduce risk. Each of these components, such as the thrust, engines, tail rotor or wing, are instrumented to be measured independently, and consequently, we are able to get exactly what we want, that is, the rotor characteristics. In addition, we can change the attitude of the wing. We have dive brakes here so we can load this rotor over its full capability as we would in a wind tunnel but do it in flight. That is a coordinated effort which has never satisfactorily been accomplished. So we are going to do it in this vehicle. These are some of the——

Senator GOLDWATER. Before you go on, the Army has this coming into the inventory.

Mr. YAGGY. Not this. This is a research vehicle. Only research. This is not a production type contract.

Senator GOLDWATER. H–3?

Mr. YAGGY. This uses H–3 components for the purpose of reducing risk in the systems other than those which we were trying to address.

Senator GOLDWATER. I was out at Fort Rucker recently. I swear I was briefed on this bird as a troop carrier.

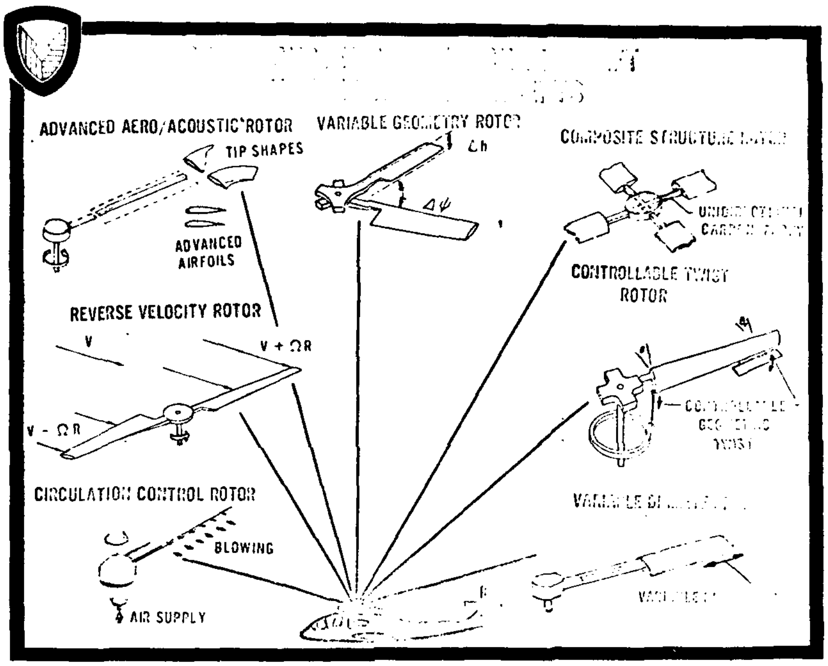
Mr. YAGGY. No, sir.

Senator GOLDWATER. It sure looks like it.

Mr. YAGGY. Perhaps you were briefed on our UTTAS.

Senator GOLDWATER. No. I know the UTTAS. I recall the H-3 and I though it was a——

Mr. YAGGY. Do not let that confuse you. It only uses some of the H-3 components to avoid the risk that is involved in the system. It is not the H-3 aircraft (fig. 10). These are some of the rotor



Page 191 Line 15

FIGURE 10

systems which could be candidates here. I point out to you the two on the lower left. Those are now being investigated by the Navy. We have close coordination with them in the area. The next two going around clockwise are specifically NASA programs and the other three are Army programs and we are taking an interservice approach to this. This will be a facility which can be used as a 10-year, 50 hours a year useful life.

Senator GOLDWATER. That variable diameter rotor, have you gotten into that yet?

Mr. YAGGY. Yes, sir. And we have been working on that. We have had contracts with Sikorsky. One of our problems has been the drive mechanism for the extraction and retraction and we have not solved that problem.

Senator GOLDWATER. How much can you vary the length?

Mr. YAGGY. We duce it by 40 percent.

Senator GOLDWATER. That would have the same effect as reducing a fixed wing once you are in flight.

Mr. Yaggy. Yes, sir. In this case it also has significant benefit to the dynamics of the rotor system. It makes it a smaller and less dynamically responsive system which is very important. It also tends to reduce the problems we are working on, that is, the retreating blades problem.

Next slide (fig. 11). The most advanced system we have in use

Page 192 Line 13

Figure 11

at the present time is also a joint program with the NASA and that is the tilt rotor concept represented by the XV-3 in the fifties. At that time we ran into problems we could not resolve. Because of the deliberate program between the agencies we have solved those problems where we are now ready to demonstrate this concept in flight. Its unique capability to tilt the rotors by which we obtain the characteristics of the helicopter in hover and then are able to convert to cruise flight with reduced vibratory loads and all. The problems of the helicopter, the edgewise problem, we are solving by putting it into the normal propeller mode.

Senator Goldwater. It becomes a propeller in that mode with a rotor.

Mr. Yaggy. Yes, sir.

Senator Goldwater. And lift value. Can you hover as a conventional helicopter using cyclic control or——

Mr. Yaggy. Yes, sir.

Senator Goldwater. [continuing]. Down wash.

Mr. Yaggy. Yes, sir, that is right. It operates just like a sideways tandem helicopter in this mode and the controls on the rotor phase

out as it transitions into forward flight. So it operates as a conventional propeller mode and you have the normal aircraft control surfaces.

Senator GOLDWATER. Is there a difference in the RPM in the two modes?

Mr. YAGGY. Yes, sir. Down to 70 percent in the cruise mode of the hover tip speed.

Senator GOLDWATER. How far along is this?

Mr. YAGGY. This is coming up for critical design review very shortly and will fly in 1976.

Senator GOLDWATER. Who is going to do it, do you know yet?

Mr. YAGGY. Yes, sir. The Bell Helicopter Co. has the award.

Senator GOLDWATER. I have seen the one made in Canada with the wing.

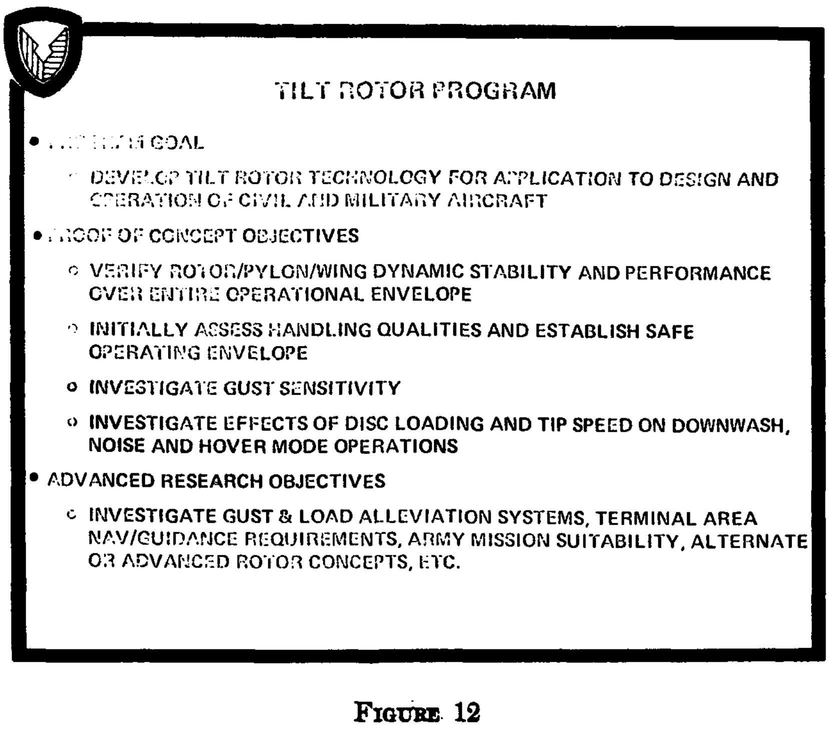
Mr. YAGGY. Canadair CL–84, yes, sir.

Senator GOLDWATER. Have you tested that?

Mr. YAGGY. We have been involved in testing with NASA in those areas and we have used the data and, of course, it all goes back to the triservice program which I am sure you remember which incorporated all of these concepts and resulted in the XC–142 which was a variable tilt wing. The CL–84 then came from that same area.

Senator GOLDWATER. That is a propeller mode throughout.

Mr. YAGGY. Yes, sir, and it has characteristic propellers. It has the characteristics of the heavier disc loading of propellers rather than the lighter disc loading which is characteristic of the tilt rotor. This chart (fig. 12) indicates, by the way, the first objective, is to



Page 194 Line 11

FIGURE 12

verify rotor/pylon wing dynamic stability and performance over the entire operational envelope. By analysis and wind tunnel testing we have confidence we have resolved that problem and are able to deal with some problems such as sensitivity characteristics, assessing the handling problems and the other items you see there.

Senator GOLDWATER. What shaft horsepower are you going to get on your first bird?

Mr. YAGGY. The shaft horsepower is—Dick, do you remember?

Senator GOLDWATER. 600?

Mr. YAGGY. No, sir. I should know that but it does not come to mind.

Senator GOLDWATER. You can provide the answer.

[The information referred to above follows:]

The first vehicle is powered by two vertical running T-53-L13 engines, each developing a takeoff power of 1,550 shaft horsepower and a normal rated power of 1,250 shaft horsepower.

Mr. YAGGY. Yes, sir. The other item I want to call to your attention as far as the Army is concerned, is right down at the lower right corner of the slide, Army mission suitability is our whole goal here. This vehicle is not a prototype. It is for the purpose of demonstrating technology. It has a long useful life. There are two vehicles being obtained and they can be used to look at both the civil and military missions.

Next slide (fig. 13). This indicates the comparison of the systems including the tilt wing which you mentioned which is the bottom one.

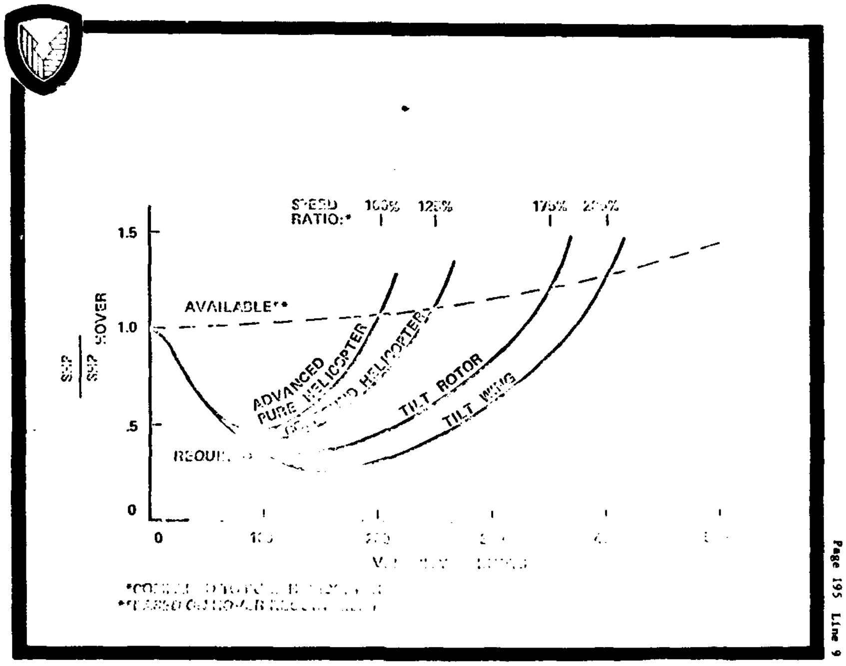


FIGURE 13

The characteristics are shown here. This is the shaft horsepower at a hover compared with the shaft horsepower at any condition at cruise flights. These are normalized so they are not necessarily the same power but it indicates the lower levels relative to the hover requirements for these advanced cases which not only gives us better economy but result in lower dynamic loading on the drive systems and consequently, longer life.

Next slide (fig. 14). Just a few other characteristics.

NOISE CO[illegible] PAYLOAD AIRCRA[illegible]

	SINGLE ROTOR HELICOPTER	TILT ROTOR
HOVER AT 500 ft DISTANCE	95 dB	95 dB
CRUISE FLIGHT AT 1000 ft DISTANCE	110 dB ROTOR BANG	C5 [illegible] NO ROTOR [illegible]
DETECTION TIME IN CRUISE AT LOW ALTITUDE	30-60 sec	5-10 [illegible]c

Page 195 Line 18

F[illegible]4

There is no improvement in noise at a hover but significant reduction in noise in cruise flight and this is especially important to us in detectability.

Senator GOLDWATER. Wait just a minute before your next slide. You get no rotor bang out of a tilt rotor?

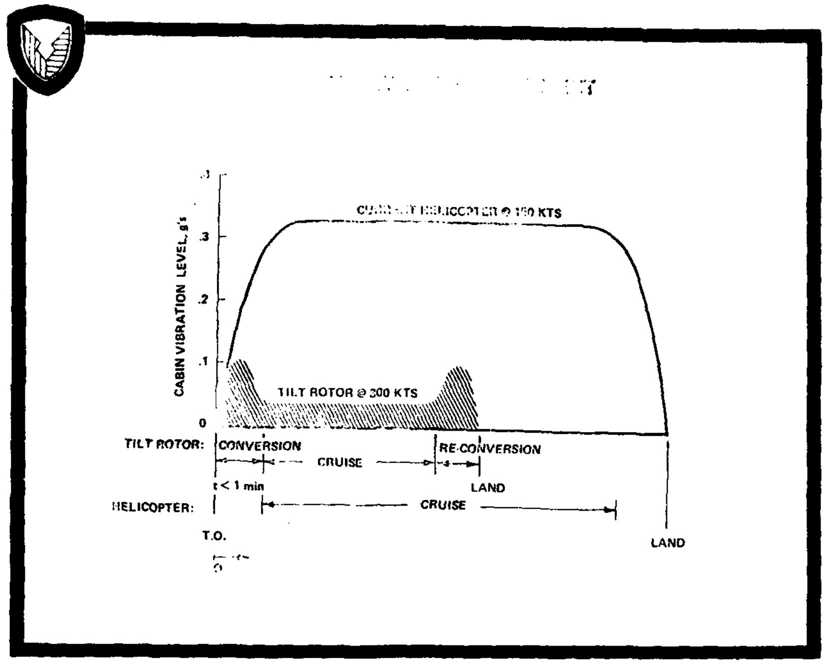
Mr. YAGGY. No, sir, because the bang comes out of the edgewise advancing of the rotor system through the air. It is the interaction at tip vortices with the preceeding rotor.

Senator GOLDWATER. They offset each other.

Mr. YAGGY. In this mode the inflow is such that there is no such interaction.

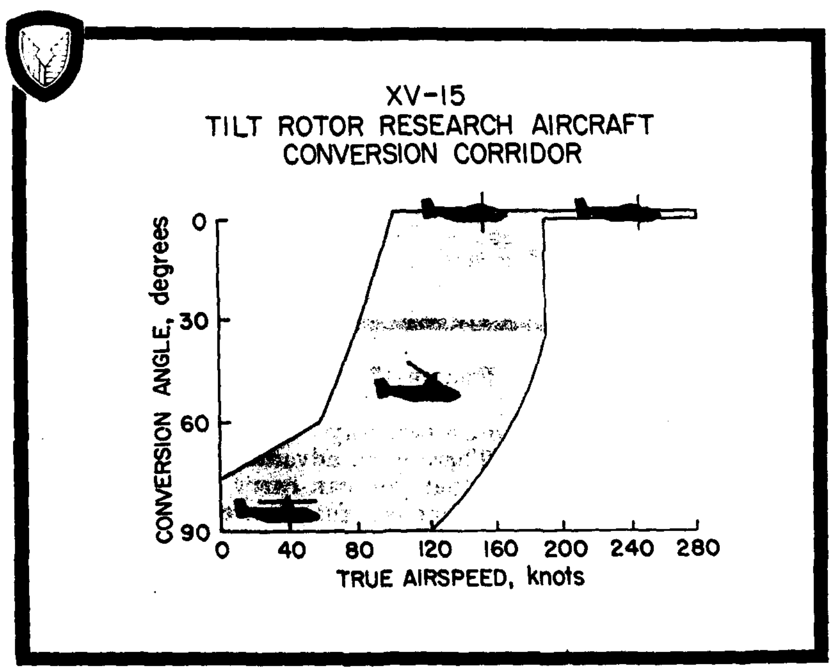
Senator GOLDWATER. All right.

Mr. YAGGY. Next slide (fig. 15, p. 167). Also shown is vibration environment. Of course, the time subjected to vibration is shorter because of the higher speed but there is a very significant reduction in vibration which improves the reliability, reducing crew fatigue. It makes for better gun platforms, because of the characteristics associated with it.



Page 196 Line 5

FIGURE 15



Page 196 Line 11

FIGURE 16

Next slide (fig. 16, p. 167). Most important perhaps is the tilting, conversion corridor, which means the attitude of the rotor at any given point. You can see it is at least 60 knots wide at any place. This shows you can operate with great flexibility. You are not transitioning in that mode. You can stop and go back. You can operate with higher agility. Of course, the tilt rotor mode gives you a better lifting component than the fixed wing mode. So for our missions in the places where we need high agility, close to the ground, evidence is——

Senator GOLDWATER. You still have the ground effects?

Mr. YAGGY. Yes, sir. It still has the same type of ground effect. The only thing that is different is there is some downwash on the lifting surface.

Next slide, please (fig. 17). This indicates the productivity com-

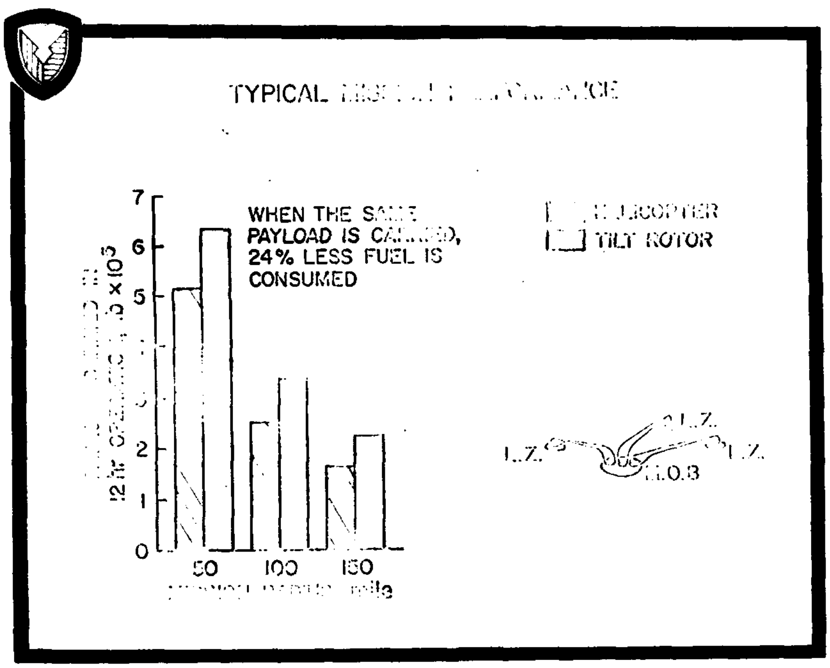


FIGURE 17

Page 196 Line 24

parison and you notice it is done two ways. This is payload carried in any given 12-hour period. There is an advantage there. But what is even more critical today is that you can carry the same load in that period of time with 24 percent less fuel. Since fuel is becoming such a critical item there is a significant advantage to the system.

(Slide) (fig. 18, p. 169). The final item I would like to address is the engine area. I am sure you are acquainted with the gas turbine engine slated for the Advanced Attack Helicopter and UTTAS. It has resulted from a 1,500 SHP demonstrator program which we

FIGURE 18

performed recently. It is the Army's responsibility to develop small engine technology. That has been assigned to us by *ODDRE*. Based on the success of this program and requirements for technology in the size of from 1 to 5 pounds per second flow engines, which is 120 to 825 horsepower, we have embarked upon a program shown in the next slide (fig. 19). The upper part shows the two contractors

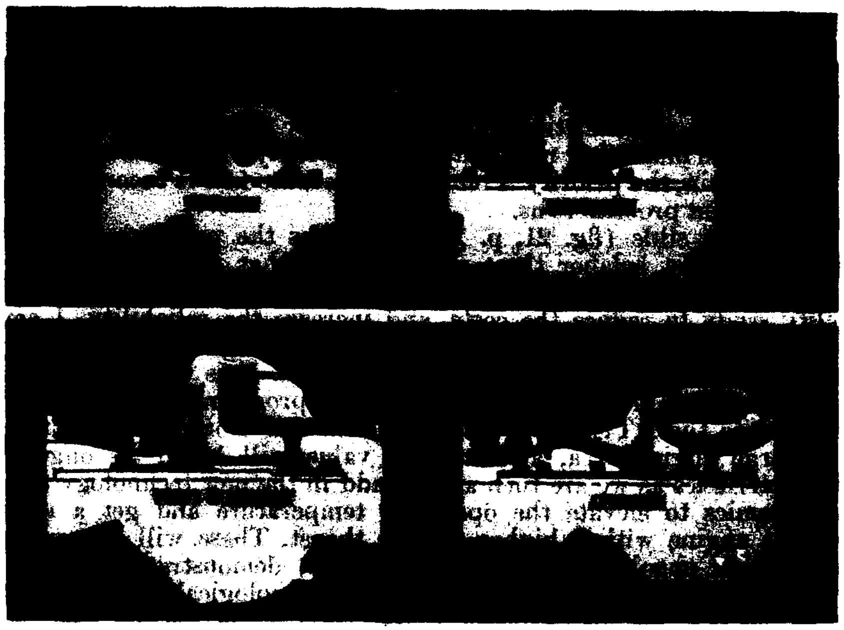


FIGURE 19

selected, Williams and Airesearch for the 1 to 2 pound per second category and lower, and the two contractors, Pratt and Whitney and Lycoming, for from 3 to 5 pounds per second. These programs are currently underway in a 4-year effort and are being carried out. The next slide (fig. 20) indicates the benefits we are hoping to achieve. By

STAGG ENGINE-FAMILY-OBJECTIVES

1. DEMONSTRATE (INTEGRATED) ADVANCED COMPONENT TECHNOLOGY
2. DEMONSTRATE CAPABILITY OF A SPECIFIC COMPONENT, WHILE MAKING OTHER TECHNOLOGICAL ADVANCEMENTS
3. TO PURSUE ADVANCED COMPONENT/SYSTEMS TECHNOLOGY INTEGRATION/DEMONSTRATION IN REAL ENVIRONMENTS-IN LOWER RISK ENVIRONMENTS
4. TO PROVIDE A LOGICAL HOME FOR 6:22 COMPONENTS OR SYSTEMS THAT HAVE RECEIVED 'DIPLOMAS' OR HAVE DEMONSTRATED THE CAPABILITY OF 'GETTING THERE'
5. TO PROVIDE DEMONSTRATED GAS GENERATOR/ENGINE TECHNOLOGY 'ON-THE-SHELF' FOR FUTURE AIRCRAFT/OTHER APPLICATIONS
6. TO PROVIDE VARIOUS DEGREES OF TECHNOLOGY AND FEATURES FOR FUTURE APPLICATIONS

Page 197 Line 20

FIGURE 20

actually demonstrating advanced component technology, specific fuel consumption as a function of the horsepower can be significantly reduced while increasing reliability and simplicity of engines and accessories. Again, the priority is on the fuel because fuel is becoming such an important problem to us.

The next slide (fig. 21, p. 171) indicates the program elements. and I will not belabor these except to say that we are now down to the testing phase. In addition we will follow this with a producibility study to reduce the costs, and increase the reliability. I emphasize that this is only a gas generator program, compressors, high pressure turbine and seals and bearings. It is the core engine. Our purpose in doing this is to establish a program that is ongoing. Similar to the ATEC program which the Air Force carries out in the large engine area, and its real value will be in its ongoing characteristics as we are then able to add in the new technology such as ceramics to elevate the operating temperature and get a more specific engine with a higher specific thrust. These will be carried on in this ongoing program. Here again, demonstration, we believe, is the essential product of the technological development. Without the demonstration and associated reduction in risk, we

ADVANCED SMALL AXIAL TURBINE TECHNOLOGY PROGRAM

DESIGN POINT PARAMETERS

TIT = 2200-2500°F	DESIGN LIFE ≥ 750 HOURS AT DESIGN TEMP.
ΔH = 170-200 BTU/LBM	LOW CYCLE FATIGUE LIFE ≥ 15,000 CYCLES
W_A ≅ 5 LB/SEC	

APPROACH

PHASE I - PRELIMINARY DESIGN

PHASE II - TURBINE CASCADE INVESTIGATION

PHASE III - STAGE INVESTIGATION

PHASE IV - DESIGN TECHNIQUE ASSESSMENT

PHASE V - MODIFICATION AND TEST

Page 198 Line 1

FIGURE 21

cannot bring our program to a sufficiently low risk to assure accomplishment within cost. So this emphasis is characteristic right from our fundamental research to our development phase.

That concludes my briefing. I will be glad to answer any other questions.

Senator GOLDWATER. I think you answered this in a way but I would like to get it a little more clearly on the record.

As you know, the Navy is working on the concept of the circulation control rotor.

Mr. YAGGY. Yes, sir.

Senator GOLDWATER. I saw this last year and I was very impressed with it. I was wondering if you have worked with the Navy, kept up on this concept.

Mr. YAGGY. Yes, sir. I would like to give you in just two or three sentences the whole history of that. We operated with Giravion Dorand Corporation of France for many years on a concept known as the jet flap rotor which is also a circulation control concept and we have done extensive work in this area, again in the latter period in connection with NASA, and have a large amount of data available. It is the work which resulted in the circulation control rotor in England. We had followed that very closely but because of its deficiencies, we decided not to invest large sums of money in it.

Mr. Williams of the Navy Ship R. & D. Center at Carderock, Maryland has been active in this program and we maintain a continuing liaison with him. Our purpose is to allow one agency to

38-266 O - 74 - 12

fund this until we have proven its capabilities and then, if it looks to be what it purports to be, we intend to get in jointly with them and develop that extensively. It is a fine concept. Its primary drawback at the present time is ability to control the rotor. This is a significant problem that has not yet been resolved.

Senator GOLDWATER. I am glad you are working with them. If it does work out, it will be a great step forward.

Mr. YAGGY. Yes, sir, it will.

Senator GOLDWATER. Eliminating a large number of problems at your hub.

Mr. YAGGY. I point out one other thing. There are two concepts of this sort of device. One is where the rotational drive is provided from the jet and that is the type that we had been investigating previously. The other, and we feel the only viable method for efficiency, is to shaft drive this device and then you have to provide the circulation control in addition to that.

Senator GOLDWATER. Do you not have a problem in that jet concept of maintaining the heat of the gas to the point that it leaves the rotor?

Mr. YAGGY. Yes, sir.

Senator GOLDWATER. I understand nobody has come up with an idea yet whereby they can keep that gas hot.

Mr. YAGGY. No, sir. We looked extensively at this drive years ago in the XV-9 with the Hughes Company. We used this type of drive. We looked at it again in the HLH. The larger the vehicle becomes, the heavier the transmission, the more attractive the drive becomes but it is still not attractive enough to us at this time. It will require significant research in order to make it a viable solution.

[Mr. Yaggy's complete statement follows:]

PREPARED STATEMENT OF PAUL F. YAGGY, DIRECTOR OF RESEARCH, DEVELOPMENT AND ENGINEERING, U.S. ARMY AVIATION SYSTEMS COMMAND

U.S. ARMY NEW TECHNOLOGY AND IMPROVED CAPABILITY IN AVIATION SYSTEMS

Over the past decade, the U.S. Army has expanded its utilization of aircraft to a significant degree because of the operational versatility demonstrated by the helicopter and its unique hovering and vertical flight capability. A wide variety of applications have clearly defined the need for VTOL operational capability and demonstrated that it is irreplaceable by other means of transportation. This expanding role of aviation has generated technology requirements which exceed the current state-of-the-art, particularly, that which deals with rotary wing aircraft, which are most germane to U.S. Army requirements.

Available technology has always been the pacing factor in meeting demonstrated military requirements. Seldom can justification be developed for proceeding into production with technology exceeding a demonstrated state-of-the-art. Therefore, improved capability generally is only attained when foresight has been demonstrated in acquiring and demonstrating technology to reduce the risk to an acceptable level. A prime consideration in this process is the ability to predict reasonable goals for design-to-cost, and to assure accomplishment of programs not only within projected costs, but to demonstrate a reasonable life cycle cost as well.

The accomplishment of these purposes requires the establishment of definitive goals. The U.S. Army has established aviation goals as is shown in Fig. 2. It is a continuing requirement to increase mission effectiveness through greater performance and increased agility. These factors are also essential to providing adequate safety, survivability, and reduced vulnerability. However, the attainment of these goals without the additional attainment of

proper dynamic response, adequate and long life structural integrity and a reliable system, results in a situation of high potential but little kinetics. Finally, acquisition and life cycle costs must be a continual consideration in the trade-offs against these goals to assure sufficient quantities and to justify the utilization of the concepts.

The U.S. Army pursues these goals through national and international endeavors, both in-house and with industry, Air Force and Navy. This research includes fundamental investigations in the basic discipline areas as well as development of analytical techniques and hardware concepts which offer potential solutions to known or anticipated problem areas and deficiencies. Facilities such as wind tunnels, whirl towers, ground based and flight simulators, and computer modelling are employed in these research programs. However, adequate demonstration of these efforts in the flight environment must be accomplished to assure the reduction of risk to the level acceptable for confident application. Since the scope of the technology and concepts programs of the U.S. Army is too vast for presentation within the allotted period, three flight demonstrators and a demonstration propulsion program have been selected to portray the character and spirit of Army efforts for new technology and improved capability. These, as portrayed in Fig. 3, are the rotary wing Advancing Blade Concept, the Rotor Systems Research Aircraft for rotor concept demonstrations, the Tilt Rotor Research Aircraft, and the Small Turbine Advanced Gas Generator engine demonstrator program.

THE ADVANCING BLADE CONCEPT

The Advancing Blade Concept (ABC), Fig. 4, is a coaxial, counterrotating hingeless rotor with several potential advantages, when compared with conventional rotary wing configurations. These advantages (Fig. 5) are: (1) high speed capability when configured as a compound helicopter with auxiliary thrust: (2) improved maneuverability, especially at low speeds; (3) elimination of the tail rotor, a hazard in both flight and ground operations; (4) reduced maintenance requirements; and (5) compact configurations.

Both the high speed capability and improved maneuverability are a direct result of the ABC unique aerodynamic lifting configuration. With this concept (Fig. 6), the aerodynamic lift in forward flight is carried on the rotating blades advancing into the oncoming airflow and is not limited to that which can be developed on the blades retreating from the oncoming flow which are limited by the reduced airflow over the blades, as is the case with conventional single rotor configurations. Thus, this concept reduces the problems of retreating blade stall and greatly enhances the amount of lift that can be provided during maneuvers. Further, the hingeless rotor system provides greatly improved controllability in all flight regimes because of its ability to carry loads with centers at large offsets from the rotor shaft.

As with other coaxial helicopters, a tail rotor is not required for antitorque purposes. Yaw, or directional control in the ABC configuration, is produced by applying differential pitch to the two rotors and thus, producing a greater and lesser torque on each of the two rotors. Elimination of the tail rotor has direct effects on operational suitability in confined areas, on acoustic signature, and on maintenance.

The hingeless rotor without flapping hinges, lead lag hinges, and associated hardware, eliminates the maintenance and first cost normally associated with these components. The very high stiffness blades are designed with a titanium main spar and a fiberglass aerodynamic "glove" to form the airfoil section. This composite construction has greatly reduced vulnerability characteristics, and also permits rotor slowing for high speed applications where the blade tip mach number must be below approximately 0.85.

Elimination of the tail rotor, when combined with the higher efficiency of a coaxial rotor, permits a smaller, more compact configuration to accomplish the same mission.

The distinct advantage in forward flight capability is shown in Fig. 7. This advantage is solely due to the design features of the ABC rotor as described above. Simply compounding a single rotor helicopter with auxiliary power will not approach this capability.

The current program has included extensive model tests, full scale wind tunnel tests, and full scale ground and flight tests. First flight was con-

ducted on 26 July 1973. After 4½ hours of hover and low speed flight, Ship No. 1 experienced extensive damage in an uncontrolled crash. Since that time, extensive flight test data analysis, wind tunnel testing, and simulation have been conducted, and the cause of the crash determined. Design modifications to alleviate the earlier deficiency have been developed and the program is being restructured to pursue the initial program objectives with Ship No. 2.

This event clearly demonstrates the value of a technology demonstrator program to reduce technological risk. The problem was one that could not have been foreseen prior to operation in the flight environment. Significant knowledge of this fundamental issue has been gained by the subsequent tests, applicable not only to this project, but in a general sense as well. Occurrence of such an event in a preproduction prototype, fully equipped with sophisticated weaponry and auxiliary systems, would have been extremely costly.

ROTOR SYSTEMS RESEARCH AIRCRAFT

Since the mid-1950's, the Army and the NASA have conducted several independent studies to determine methods of improving the capabilities of rotor flight research on an economical and timely basis. Results of these studies prompted the establishment of an Army/NASA working group in January 1971 to determine if a commonality existed in both agencies for rotor flight research, and if so, what system or facility would best provide a capability to achieve research objectives. It was concluded that an instrumented flying test bed concept offered the best solution. The Army/NASA team subsequently agreed upon the performance criteria and characteristics of a test vehicle that would fulfill the flight research objectives of both agencies. A government technical and cost risk analysis was completed in August 1971 to determine the probability of success in developing a Rotor Systems Research Aircraft (RSRA, Fig. 8). To determine the feasibility of the RSRA concept, a competitive solicitation was released to industry in August 1971 for two independent predesign (feasibility) studies of the RSRA concept. In addition to the feasibility assessment required from the contractors, program costs and schedules for a RSRA, accompanied by an *independent risk analysis*, were also required. To assure program continuity and joint agency commitment, the Army and NASA entered into formal agreement on 1 November 1971 to jointly develop and utilize the Rotor Systems Research Aircraft. The predesign studies were completed in August 1972, concluding that the RSRA concept was feasible and within the state-of-the-art. Although different technical approaches were submitted by the contractors, the vehicle configurations were very similar. Also, technical and cost analyses confirmed the government's in-house estimate. Satisfied with the findings of government and industry efforts, the Army and NASA in November 1973 selected, by a competitive solicitation, Sikorsky Aircraft to design, fabricate, and demonstrate the RSRA.

Objectives

The objectives of the Rotor Systems Research Aircraft program (Fig. 9) are to provide those agencies of the government charged with the responsibility of developing rotor technology, with a flying research tool having sufficient versatility to provide the necessary in flight verification of supporting rotorcraft technology as well as to test a wide variety of new rotor concepts. One of the prime considerations of the program is that this research capability be cost effective and timely. These aircraft will provide research capability that cannot be duplicated in ground based facilities and which have been previously restricted because of the expense of specialized vehicles.

The design criteria for the RSRA have been established to insure attainment of the broad research objectives of rotorcraft technology verification including flight research on new rotor concepts. The aircraft design will be flexible enough to permit the installation and testing of many new rotor concepts which are now in various stages of development by various government agencies. It will also allow parametric variation of such things as disc loading, tip speed, and cruise conditions for each of these rotors.

The key to the RSRA design philosophy (Fig. 10), and its value as a reseasch test bed, is the capability for data acquisition and accuracy. The aircraft is designed around a highly accurate rotor force and moment balance

measurement system which isolates the rotor/transmission from the vehicle. To complete the quantification of the rotor state, force measurements systems are installed on the wing, tail rotor, and auxiliary propulsion system.

Implementation plan

The RSRA concept dictates that the aircraft be capable of operating a rotor under closely controlled and specified flight conditions with adequate provisions to accurately measure the rotor and air vehicle characteristics in maneuvers as well as forward flight. In order to obtain this capability, the RSRA will be equipped with a computer controlled, automatic flight control.

One of the most significant areas of research for the RSRA will include quantified data for substantiation of analytical prediction techniques. True potential of rotorcraft application and utilization cannot be realized until their limitations are documented and understood. The unique features of the RSRA will provide the first true capability to explore and document the full potential of various types of rotors. Flight research for analytical prediction technique substantiation in such areas as rotor stability boundaries and aeroelastic characteristics, rotor maneuvering envelopes, rotor performance capabilities, and drag interference effects will increase the design confidence of new rotary wing vehicles. The RSRA will also be used to demonstrate new structural concepts and techniques for reduced maintenance, increased reliability, and increased safety and survivability. The RSRA will also be used to verify the potential of new rotor concepts (Fig. 11) resulting from the technology studies such as the variable diameter rotor, rigid coaxial rotor, slowed and stopped rotors, new composite materials rotors, supercritical and laminar airfoil rotors, optimum geometry rotors involving varying chord, twist, camber and airfoil shape as a function of span, as well as varying blade azimuth and vertical spacing. In addition, techniques offering potential solutions to aerodynamically generated noise, tip compressibility effects, vibration isolation, and integrated non-linear control systems will be economically verified through coordinated utilization of the RSRA. It is anticipated that the RSRA will be utilized for 12 years at an anticipated rate of fifty productive research flight hours on each aircraft per year.

TILT ROTOR RESEARCH AIRCRAFT

A major problem in rotorcraft is the high dynamic loads experienced by the helicopter rotor during cruise operation. These high dynamic loads not only restrict the performance capability of the helicopter but, more importantly, generate the vibrations and noise that result in the fatiguing of structures, components and aircrew, reduced availability, and increased maintenance and support costs. Moreover, in addition to the VTOL capability requirement, several of the Army air mobility missions would benefit greatly from the increased productivity that a higher cruise speed could provide. The tilt rotor aircraft concept offers promise of significant improvement in these areas while providing the desirable VTOL characteristics of the low-disc-loading rotary wing aircraft. Therefore, over the past five years, the Army has actively supported a program to develop the technology required to enable the implementation of this type of air vehicle. Knowledge in all key disciplines has now advanced (through full-scale component experimental investigations) to the point where the flight demonstration of the integration of all technologies is warranted. A program to accomplish this has been developed jointly with the NASA. This activity is known as the XV-15 Tilt Rotor Research Aircraft Project (Fig. 12).

Objectives

The following proof-of-concept objectives, directed toward basic tilt rotor air vehicle technology verification, have been established for the current XV-15 Rotor Research Aircraft Project (Fig. 13).

a. Experimentally explore, through flight research, current tilt rotor technology which is of interest for the development of useful, quiet, and easily maintainable Army tilt rotor aircraft. Verification of the rotor/pylon/wing dynamic stability and aircraft performance over the entire operational envelope are key elements of this objective.

b. Experimentally establish a safe operating envelope and initially assess the handling qualities of the Tilt Rotor Research Aircraft as a basis for the follow-on advanced flight research.

c. Investigate tilt rotor gust sensitivity.

d. Investigate the effects of tilt rotor disc loading and tip speed on downwash and noise and the impact on hover mode operations.

An advanced flight research program has been formulated to expand the state-of-the-art of tilt rotor handling qualities, operations and configuration design. These flight investigations will be performed to achieve the following objectives:

a. Incorporate and evaluate gust and load alleviation systems.

b. Perform thorough evaluation of the handling qualities of the Tilt Rotor Research Aircraft and assess areas where additional tilt rotor handling qualities research is required.

c. Provide data for consideration of design and operational criteria and mission suitability for potential Army production tilt rotor aircraft.

d. Investigate alternate or advanced rotor concepts or configuration modifications.

As part of investigating mission suitability, all related technological characteristics such as maintenance, human factors and safety will be explored. Further flight research will be performed with the Tilt Rotor Research Aircraft to explore the various aspects of use of this concept for typical Army missions—the ultimate Army objective of this program.

Concept characteristics

The principal flight modes of the tilt-rotor aircraft are hover/helicopter, transition and cruise. The two tiltable low-disc-loading rotors, located at the wing tips, are driven by two or more gas turbine engines. The engines may be located in the tilting nacelles mounted at the wing tips, or may be fixed with respect to the wing. A cross shaft system mechanically links the rotors so that power sharing for maneuvers or control is possible and asymmetric thrust in the event of single engine malfunction is avoided. Independent control of each engine/rotor can be maintained should simple cross shaft failure occur (due to combat damage, for example). The rotor/nacelle tilt mechanism is provided with redundant fail-safe design features, thus preventing asymmetric tilt conditions and binding of the mechanism in any fixed position. The stiffness and mass distributions of the rotor/nacelle/wing/dynamic drive system are tuned to avoid resonances in the range of operating rotor rotational speeds. Special emphasis is placed on meeting both the structural and dynamic stability requirements. Therefore, the aircraft is free of rotor stall flutter and wing/pylon/rotor dynamic coupling problems throughout the entire tilt rotor operational flight envelope. The control system in hover is similar to that of a "side-by-side" twin rotor helicopter. Cyclic pitch provides longitudinal control and (differentially applied) yaw control, eliminating the need for a tail rotor. Differential collective pitch provides roll control. In the cruise flight mode, control is achieved with conventional airplane control surfaces, although the rotor controls can also be used in cruise for control augmentation, aircraft stabilization, and gust alleviation. A program for phasing of control functions from helicopter to aircraft type controls as a function of mast angle is applied during conversion. The relatively short duration of high speed forward flight in the helicopter mode for most applications results in a favorable fatigue environment for the tilt rotor aircraft as compared to a helicopter. Therefore, high reliability and low maintenance are anticipated. In the hover mode, tilt rotor vehicles operate at low power levels and consume less fuel than other VTOL concepts (with the exception of the helicopter) because of the high lift efficiency of the low disc loading rotors. The resulting low downwash velocities allow efficient operations to be performed below hovering tilt rotor aircraft with improved personnel safety. The low disc loading rotor also provides autorotation capability for emergency descent in the event of total power loss. During the conversion process to the cruise mode, rotor tip speed is reduced to approximately 70 percent of the hover value. Cruise propulsive efficiency (Fig. 14) is therefore increased and cruise noise levels are reduced while engine performance and transmission/drive system torques are maintained at desirable levels. In addition, the moderate tip speeds and low nonoscillatory blade loadings of the tilt rotor result in noise levels in hover and cruise (Fig. 15) that would reduce acoustic signature and detection compared to other VTOL concepts.

The tilt rotor concept eliminates the need for continuous edgewise flight of the rotor, which produces detrimentally high dynamic blade loads and the deterioration of propulsive efficiency at moderately high speeds. The use of the wing to sustain lift in the cruise mode permits reduced load on the rotors which improves flying qualities and, by lowering cabin vibration levels (Fig. 16), reduces crew fatigue. Perhaps the key potential advantage of the tilt rotor concept is the ability to provide cruise speeds in excess of 300 knots while retaining the efficient hover and VTOL capability of the helicopter.

The tilt rotor concept is also unique in that the conversion corridor, (i.e., the band between the minimum and maximum flight speeds throughout the rotor-mast tilting process), is broad (typically greater than 60 knots) and non-critical (Fig. 17). Furthermore, the conversion may be stopped and reversed, or the aircraft may be flown steady state at any point in the conversion corridor. This feature is expected to provide great flexibility in field operations, enhance survivability because of low-speed agility, and permit the performance of STOL operations at greater than VTOL gross weights.

The tilt rotor holds promise for both increased responsiveness and for reduced fuel consumption (Fig. 18), both of which are vital to Army operations.

Implementation plan

The plan to accomplish the necessary technical goals is composed of the following eight elements which are required prior to entering a production prototype program:

1. Methodology development.
2. Model tests.
3. Full scale component and subsystem tests.
4. Air vehicle design studies.
5. Flight simulation investigations.
6. Systems integration and proof-of-concept flight tests.
7. Advanced technology investigations flight tests.
8. Mission suitability flight tests.

Flight simulation investigations have been planned and initiated throughout the tilt rotor program. The simulations provide a means of assessing handling characteristics, configuration variations, flight operation procedures, emergency procedures and SCAS and gust load alleviation system charactiristics. The simulators will also be used for pilot familiarization.

The fabrication and proof-of-concept flight tests of the research aircraft are important milestones in the Army tilt rotor technology program. Basic flight safety and flight envelope boundary exploration will be conducted by a contractor. Additional flight research to examine structural stability, assess handling qualities and study generic tilt rotor aircraft flight characteristics and the effects of gusts, tip speed and disc loading will be performed jointly with NASA. These flight investigations from the foundation for the advanced flight research program.

The Army and NASA will continue with the joint flight test program beyond the basic proof-of-concept flights. Research into gust and load alleviation systems, handling qualities, and alternate or advanced rotor concepts are planned. The data resulting from this investigation may be instrumental in formulating design and operational criteria and specifications for Army air mobility tilt rotor applications. Certain flight phenomena may warrant additional analytical investigations, model tests, flight simulations, and further flight tests.

The Tilt Rotor Research Aircraft will be used as a tool to assess Army air mobility mission suitability. Factors such as hover out-of-ground-effect, climb capability, loiter and cruise performance, maximum speed capability, handling qualities, maneuverability, pilot workload, autorotation capability, maintenance requirements, and noise, radar, IR and visual detection signatures will be examined. Although the XV-15 Tilt Rotor Research Aircraft is not optimally sized or configured for the particular requirements for any specific Army air mobility mission, the vehicle is sufficiently versatile to demonstrate and explore many of the various mission performance and operation factors. The Tilt Rotor Research Aircraft is also a suitable test bed for advanced VTOL avionics for all-weather operation and area navigation investigations.

The application of the STOL mode and the use of intermediate rotor mast positions will be studied during this flight test period.

SMALL TURBINE ADVANCED GAS GENERATOR (STAGG)

The Army has assigned responsibility, by interservice agreement, for the advancement of technology and the development of small engines. Recently, the Army successfully completed a demonstrator program on a 1,500 horsepower engine which resulted in the General Electric T700 engine (Fig. 19) to be used in the Army advanced attack helicopter and the utility tactical transport helicopter. Based on this successful approach and in response to a requirement for small engines in the 2 to 5 pounds per second airflow range, the Army has initiated a four-year program for the design, fabrication and testing of the Small Turbine Advanced Gas Generator (STAGG), with four different contractors (Fig. 20). Williams Research and AiResearch are working in the airflow range of 1 lb/sec to 2 lb/sec, corresponding to power levels of 120 hp to 290 hp; Lycoming and Pratt and Whitney-Florida are investigating the range of 3 lb/sec to 5 lb/sec, encompassing power outputs from 465 hp to 825 hp. The configurations are, in fact, scaleable to sizes ranging from 120 hp to 1,850 hp with considerable assurance of success. The primary goals of the STAGG program are the demonstration of greatly improved specific power output and specific fuel consumption (Fig. 21).

The Army's interest in small gas turbine engine technology (1 to 15 lb/sec airflow size) is based on two major factors: first, over 85 percent of the aircraft gas turbine engines in the Army inventory are under 1,500 hp; and second, the small engine has been unable to utilize directly the advanced technology from large engine research and development due to inherent geometry and size limitations.

The program includes hardware and testing of the gas generator only—the compressor, combustor, high-pressure turbine, bearings and seals. Studies are also included which determine producibility, reliability and maintainability, and cost (Fig. 22).

The STAGG program has now progressed through the initial testing of the gas generators. The ultimate benefits of STAGG will be realized by converting the present program, which started in 1971, into a program continuing the updating of the gas generator (similar to the ATEGG program). Such a program will incorporate advanced technology components into the gas generator as they become available, and will maintain the gas generator technology at a current level.

Senator GOLDWATER. General, do you have any comments?

General COOKSEY. Yes, Mr. Chairman. I heard earlier some comments that were made about producing alcohol from organic waste. We have discovered a fungus that can be used to transform or process cellulose into alcohol and I think how we found that is particularly interesting. We found an old cartridge belt in New Guinea that had been out there since World War II and found this fungus on that belt. The work is being done at Natick Labs in Massachusetts, and we are working on a pre-pilot production facilities to do this and we are right now estimating that in about 18 months we will be able to really demonstrate the capabilities, in a reasonable circumstance, to produce alcohol.

Senator GOLDWATER. Do you have any papers on it so far that I could——

General COOKSEY. I would like to submit something for the record, if I may, on this program.

Senator GOLDWATER. I wish you would. I wish you would give me a set, too.

General COOKSEY. All right, sir.

[The information referred to follows:]

Included within the mission of the US Army Natick Laboratories is the responsibility to conduct research to reduce or prevent the deterioration of military materiel. In pursuing this work, it was confirmed in the late 1960's that a fungus, *Trichoderma viride,* causes microbial deterioration of packaging and other materials by producing an enzyme that converts cellulose to glucose (sugar). In 1970, a small effort was initiated to explore the potential application of this process in a controlled manner to convert waste cellulose (paper, cardboard, wood, grass cotton products, etc.) to a useful product. After the cellulose has been converted to a glucose syrup, presently available and widely used technology can be applied to convert this to other products to include ethanol (ethyl alcohol), a potential low polluting fuel.

A major breakthrough was achieved in 1971 when a mutant strain of the fungus was produced by irradiation. This particular strain produces two to four times the amount of enzyme produced by the natural fungus and will significantly improve the economic competitiveness of the process.

Considerable experimentation has been conducted to optimize the pre-processing of the cellulose waste prior to the enzyme reaction to produce the maximum yield. "Ball milling" the waste and preparation of a pulp has produced the best results.

To date the process has been used only in laboratory units in a batch mode yielding a few pounds per batch. A pre-pilot model plant was installed at Natick and became operational in June 1974. This plant will have the capacity for treating 1,000 pounds of cellulose per month to produce 500 pounds of glucose. It is planned to further optimize the process, develop the engineering data necessary to scale up the plant and produce preliminary economic feasibility data. At the present level of effort, this should be accomplished in 18-24 months.

Ethanol is a potential substitute for petroleum fuels or can be added to gasoline in varying proportions with little engine modification. However, the present methods for producing ethanol are not cost competitive with petroleum products at this time. Indications are that this process may be able to produce ethanol more cheaply than methods currently in use. However, this remains to be substantiated. From a technology point of view, a full scale operating plant should be possible by 1980.

Senator GOLDWATER. We have got a lot of that stuff lying around out there. In fact, you might look right over there in the Senate.

[Laughter.]

General COOKSEY. Please let the record show that I did not say anything.

I might add that the pre-pilot production facility is going to use primarily paper waste, newspaper and things like that.

Senator GOLDWATER. Where is that facility?

General COOKSEY. At Natick, Mass. Natick Laboratories in Massachusetts.

Senator GOLDWATER. Well, General, I think you have done a good job here and you start off by telling about Army aviation. I think I am the only one that read the Howze Board report all the way through and consequently, anything you do in aviation does not surprise me. I think the next chapter will have to do with the Air Force being issued rifles.

Thank you very much.

General COOKSEY. You are welcome, sir.

[Whereupon, at 11:50 a.m., the hearing was concluded.]

APPENDIX

Statement of Clifton F. von Kann
Senior Vice President
Operations and Airports
Air Transport Association of America
Before the Senate Committee on
Aeronautical and Space Sciences
July 25, 1974

Statement on Behalf of the U. S. Scheduled Airlines on Advanced Aeronautical Concepts

My name is Clifton F. von Kann. I am Senior Vice President, Operations and Airports, of the Air Transport Association of America. We are grateful for the opportunity to offer a statement at this hearing which we understand deals predominantly with the work NASA can do which will lay the technology base for advanced aircraft of the 1980's and 1990.

I wish to discuss four areas of interest to scheduled air transportation: the institutional roles of NASA; the achievement of higher productivity of transport aircraft; noise and propulsion research and technology; and research needed to make our aircraft better partners in the airspace and airport system.

We had the privilege of testifying earlier this year on the NASA FY-1975 Program and Budget, and our general views are contained in that statement. We indicated our strong support especially for research in the areas of materials, structures, and fluid and flight dynamics. We supported NASA's efforts on

propulsion environment impact minimization, propulsion components research, and experimental propulsion programs, and urged increases in NASA's work in aircraft operations research.

Much of the work and those recommendations apply to building the technology base for transport aircraft of the 1980's and 1990's. In our testimony we submitted a document, completed late last year, containing specific airline views and recommendations on the role we feel NASA should play in relation to our industry. This report, entitled "Views of the Scheduled Airlines on a Responsive NASA Research and Technology Program" discusses what we perceive to be NASA's roles and responsibilities, and offers a series of specific priority work areas and efforts which we feel would benefit the air transportation system in the country. The report is attached.

The Institutional Role of NASA

In considering the institutional roles NASA plays, and should play, in the improvement of the air transportation system and the aircraft we use, we perceive three basic roles:

> First, we think it is NASA's responsibility to build a technology base for aeronautics through innovative research. In this task the goal should be to utilize the best scientific minds to create innovations and to enhance our knowledge with the greatest possible independence of spirit and freedom from bureaucratic entanglement.

Second, NASA should be a problem-solver in which it undertakes directed research in response to specific problems which may be identified by NASA itself, or by others.

Third, and vitally important, is the area in which NASA's work is directly responsive to the needs of other agencies or organizations, and in which guidance and a degree of control is exercised by other agencies, but where NASA has unique capabilities or facilities which can serve identified needs.

One of our primary interests is to assure that aircraft of the future are even better partners than our present fleet with the airport and its neighbors, and the Air Traffic Control system to assure that the greatest possible efficiency of the total system can be achieved. This means that, particularly in the latter two roles it is essential that NASA work closely both with FAA and the industry and tailor its research activities to the real problems which FAA faces in creating a better Airport/Air Traffic Control system. It is essential to assure that the NASA work which comes close to the responsibilities of FAA is fully coordinated, and that the work done is responsive to problems and guidance offered by FAA, to achieve realistic cost-effective solutions to our problems.

Productivity Research

In considering the problems of the air transportation system, the area of productivity represents perhaps our greatest challenge.

In a time of rising costs of all kinds, and a precipitous rise in the cost of fuels, the achievement of more efficient aircraft is perhaps our greatest challenge. This is not a glamorous area of work, it probably represents few scientific breakthroughs - yet it is probably the most important challenge, in terms of the improvement of our American air transportation system, and in the opportunity it represents for the U. S. to remain dominant in the world marketplace for aviation products.

The work encompasses many areas and many disciplines. Among them - the development of lighter, simpler aircraft structures; research to establish the properties of new and better materials; the achievement of greater versatility of application of particular airframe and aircraft designs; the achievement of more fuel-efficient engines; achievement of quantum steps in the reliability and integrity of electronic systems used aboard our aircraft.

We have followed with interest NASA's work on supercritical wing technology. This work has now been widely publicized and the findings made known to industry. We believe this technology should now be extended into the low-speed regime. It's our understanding that the supercritical wing offers its primary advantage in the high-speed regime, but offers less, if any, advantage in the terminal area or at low speeds. In order to make this technology truly applicable to transport aicraft which must operate for extended periods in terminal areas, research should now be undertaken to optimize the supercritical wing for operation in both high- and low-speed regimes of flight.

The airlines have observed and supported NASA's technology work in the "STOL" area, and have watched with interest NASA's attempts to achieve economically viable propulsive lift.

We believe that propulsive lift technology work should continue as a technology whose fruits may be applicable to a wide range of aircraft applications. Technology efforts directed toward making aircraft better suited for terminal operations, regardless of range, are an essential ingredient in creating viable aircraft for shorthaul service. These two areas of research perhaps form a better basis for future development of economical jet-STOL aircraft than concentration on complete jet-STOL aircraft systems.

I want to call particular attention to an area of work of great promise -- aircraft digital control systems and active control concepts, in which full-time stability augmentation systems might come to permit major reductions in aircraft structural weight. The achievement of this capability, with the safety and integrity which are basic requirements in any air transport aircraft, deserves major emphasis and optimum exploitation in NASA's research and technology activities.

In sum, we envision in NASA's work on aircraft productivity a focused, multi-disciplinary effort to produce fundamental improvements in the efficiency of aircraft in military and civil aviation systems, with particular emphasis on work to reduce the cost of operations and improve the performance of aircraft. Emphasis on the operation of air transportation in the existing and prospective Air Traffic Control system will pay dividends

in terms of maintaining U. S. preeminence in aviation aerospace products. We believe a specific focal point should be created within NASA to deal with this effort.

Noise and Propulsion Research

We have often testified on the need for forward-looking research and technology on propulsion systems and noise. The reduction of noise and the achievement of better, more fuel-efficient propulsion systems remains one of our major goals and one of the major activities for NASA. We have read the statement offered by Dr. Jerry Grey of the American Institute of Aeronautics and Astronautics who appeared before the Committee on July 18, 1974; and we support the views expressed -- particularly on the need for research on new engine cycles, the variable cycle engines, and work on new fuels. While we are somewhat less optimistic about the possibilities for liquid hydrogen and nuclear propulsion than would be implied from Dr. Grey's statement, we believe that NASA's work in these areas is essential and requires strong support.

It should be kept in mind that NASA's work on advanced fuels may have applications beyond air transportation. It may turn out that ground and stationary energy users may be able to use newer fuels, such as liquid hydrogen and possibly nuclear fuels, more efficiently than can air transportation; and this indeed would be an important finding. It may be that the contribution that NASA can make will be to show that the efficiency of new fuels for stationary uses are such that they are best used for such applications - thus freeing fossil fuels for transportation.

We have long supported NASA's efforts in the achievement on quieter and more efficient engines and continue to support such work because of its importance in creating a technology base for new and quieter aircraft.

We believe it is also NASA's role to establish the noise base, i.e., the low limit beyond which the laws of physics tell us it is impractical to strive; and to work in the psychoacoustics area - to learn more about the mechanics of noise and the meaning and effect of different kinds and levels of noise on the populace living near airports. It is a proper role for NASA and one which should be exploited. As was pointed out nearly unanimously by witnesses on July 24, before the Subcommittee on Aeronautics and Space Technology of the House Committee on Science and Astronautics, there is great confusion, if not a void in the psychoacoustics area.

Making Aircraft Better Partners in the Total System

NASA should work on the technology base which will permit new aircraft to be better partners in the most effective use of our airports and airspace system. Here the relationship between NASA and the industry and FAA is critical. We think it is FAA's obligation and responsibility to work with NASA to assure there is a clear understanding of the current and prospective working of the Airport and Air Traffic Control system, and to identify those aircraft characteristics which would create the best and most efficient total system.

We are delighted to see that NASA has seen fit recently to establish an ad hoc Panel on Terminal Configured Vehicles.

It represents an opportunity for NASA and the industry to come together and understand the relationship of the aircraft to the Air Traffic Control system and, working with FAA and the industry, to establish best areas of NASA research. I want to emphasize several of the recommendations of the first meeting of that Panel. The first is a recommendation that NASA make clear its objectives for the Terminal Configured Vehicles program. The Panel recommended that NASA extend its coordination, particularly in the area of air traffic control with DOT/FAA to assure that duplication can be avoided between the work of FAA on the Airport/Air Traffic Control system and NASA's efforts.

It has been recommended, and we endorse the recommendation, that several priority areas need to be investigated -- among them pilot and aircraft system needs in the 1985 - 1990 air traffic control environment, the achievement of aircraft designs (which concentrate on reduced fuel consumption) integrated with FAA's and airlines' automated systems; human factors and oculometer research; and impact of aircraft system failure modes, failure effects, and criticality analyses on aircraft and pilot performance.

To sum up, the scheduled airlines continue to hold the belief that NASA is a vital and potent force in the achievement of a better air transportation system for the United States, and the achievement of continued superiority for America's products in the world market. The role we foresee for NASA in relation to the aircraft of the late 1980's and late 1990's is as an institution which utilizes the best scientific minds to create innovations and

38-266 O - 74 - 13

to enhance our knowledge with the greatest possible independence of spirit and freedom from bureaucratic entanglement. We expect innovative research to build the technology base for the future; but we also expect NASA to emphasize the seemingly more mundane problems of achieving higher productivity from our air transportation system. That is an equally challenging and appropriate task for NASA and for our country.

Air Transport Association OF AMERICA

Views of the Scheduled Airlines on
a Responsive NASA Research
and Technology Program

September 1973

Air Transport Association of America
1709 New York Avenue, N. W.
Washington, D. C. 20006

Views of the Scheduled Airlines on a Responsive NASA Research and Technology Program

A Report of the

Air Transport Association of America

Views of the Scheduled Airlines on a Responsive

NASA Research and Technology Program

Introduction

The scheduled airlines of the United States view NASA as a major national asset.

Scheduled air transportation owes a major debt to the National Advisory Committee on Aeronautics (NACA) which was a major force in shaping air transport technology before the major NASA emphasis on space began a decade or more ago. The airlines are pleased to see the re-emphasis within NASA on aeronautical technology, and we strongly support a vital and energetic NASA program.

A major investment is being made which should yield important results for this country and its aviation leadership. This investment is by far the largest pool of scientists and engineers working cohesively in aeronautical research and technology in the United States, and probably in the world.

Increased Emphasis on Aeronautics

The transition within the NASA organization from a predominantly-space orientation to renewed emphasis on creative and innovative aeronautical research and technology is not easy. There is a continuing risk of NASA drifting into design refinement activity which can only be done successfully on the manufacturers' competitive firing line, instead of pressing bold, innovative efforts.

Important strides are being made by NASA in this transition, and these must be continued and strengthened if there is to be full value from the NASA work. The industry, and particularly the eventual users of the NASA output, have an obligation to offer constructive criticism, as well as to lay out clearly areas which in their view would yield best results for the country from the major NASA investment.

This paper is an airline contribution to that guidance and direction.

Technology Research vs. Project Orientation

Airlines have begun to sense in recent months an important and valuable NASA trend to emphasize individual technologies. While NASA has always, and properly, rejected any intention to develop prototype aircraft, there has been a tendency which has seemed more project-oriented than is desirable. The airlines strongly

support NASA orientation toward individual technologies because we see therein the major NASA contributions, but also support research into life-reliability studies on total systems, where such work can offer prospective total aircraft system operational efficiency improvements.

Airlines believe that the close buyer-seller relationship between aircraft manufacturers and airline customers has been primarily responsible for the development of the highly successful aircraft development process in the United States; and airlines are concerned about any activity which could derogate that relationship, no matter how well-intentioned. The development and use of technology by the military services has traditionally been of great value in this process. The development of technologies which can be used in enhancing that buyer/seller process and which can yield better, more competitive aircraft in the world market, is the major contribution NASA can make to this vital national asset.

In carrying out its mission, NASA should utilize to the maximum practical extent the pool of scientific and engineering talent which the aerospace manufacturers represent. Use of this major resource not only aids in achieving NASA's research aims, but broadens the base of knowledge in industry which has been the basis of America's aviation leadership.

<u>NASA Roles</u>

The roles which NASA should play in the development of aviation advancement have been long under debate. NASA has traditionally taken, and should continue to take several roles.

In the view of the airlines, these roles, in order of importance are as follows:

1. First, the airlines believe it is NASA's responsibility to build a technology base for aeronautics through innovative research. In this task the goal should be to utilize the best scientific minds to create innovations and to enhance our knowledge, with the greatest possible independence of spirit and freedom from bureaucratic entanglement.

2. The second role should be that of problem solver, in which directed research is done in response to specific problems which may be identified by NASA itself or by others. In this category of effort the airlines see NASA again as an independent researcher, dealing with problems and hopefully arriving at solutions essentially independent of other government structures.

3. The third category is work directly responsive to the needs of other agencies or organizations, in which guidance and a degree of control is exercised by other agencies, but where NASA has unique talents, unique capabilities, or facilities which can serve identified needs.

Much of the work which the scheduled airlines see in which NASA can make major contributions to the United States may at first glance appear mundane and excessively result-oriented. Indeed much of the work does not have the easy focus of a space shot or a revolutionary, imagination-firing new aircraft; yet in these difficult, unglamorous, and often gruelling efforts lies the secret of continuing U. S. superiority in aeronautical technology and air transportation.

As the airlines see it, NASA should be the organization which keeps the United States in the forefront of research and technology, by mustering the best brains and knowledge in the United States to work on basic problems and innovations; by carefully distinguishing between basic innovative research and the more comfortable, but far less valuable engineering design enhancement; by helping to make the U. S. aerospace industry the best possible international competitor in an aviation environment which is becoming more and more competitive; and, certainly not least, by making major contributions to the efficiency and economic viability of the aviation system as an element of the U. S. transportation system.

Responsibility for Research and Development - Relationship of NASA, DOT and FAA

In the view of the airlines, NASA should be responsible for the development of a basic research and technology program to support and enhance civil aviation. NASA should utilize the best thinking of experts in and out of Government who are working in the forefront of the technology, as well as the mature recommendations of the aerospace industry and the users of aeronautical technology.

NASA should be responsive to policy guidance from the Department of Transportation and FAA as those agencies perceive the need of the Nation for research, and as enunciated in such documents as the Joint DOT-NASA Civil Aviation Research and Development Policy Study and other Government policy statements. The primary thrust and direction in specific fields of work should be supplied by the most appropriate agency.

Civil Aviation Noise Research and Development

DOT should be responsible for establishment R&D of basic objectives related to aviation noise with inputs from EPA, FAA and NASA as appropriate.

NASA should be responsible for control management and funding of noise research and development to achieve the basic objectives.

FAA's role is to assess the degree of readiness of a specific noise control technology and consider its implementation. This especially applies to procedural and operational approaches to noise alleviation.

FAA, in consultation with EPA, should be responsible for the establishment of program goals and research and development related to airport area land usage planning and control efforts.

Airframe and Propulsion Systems Research and Development for civil aircraft should be controlled, managed, and budgeted by NASA. While there must be direct lines of communication and coordination between FAA and NASA, and while FAA should be free to request specific work by NASA, basic control and management should be under NASA. FAA's role should be to deal with R&D related to basic day-to-day airworthiness problems; and to identify, and cause to be carried out, R&D efforts which relate to regulatory problems of airframe and propulsion systems.

Civil Airport and Runway Research and Development

FAA should control, manage, and budget airport and runway research and development, especially as it applies to airport layout and traffic movement efforts, and achievement of improved and rational methods of pavement design. FAA airport R&D should be limited to the area within airport boundaries. FAA should utilize the services of NASA and other agencies with specific expertise (such as the military services) in runway technology efforts as appropriate.

Airway and Air Traffic Control Research and Development

FAA should control, manage, and budget this work. Responsibility and authority for conduct and results of this effort should be FAA's. Separate efforts by other agencies, such as DOT and NASA, to undertake airway and ATC research and development, should be discouraged in order to minimize duplication of effort. Valid NASA efforts which fit into the broader FAA development effort should be supported, but they should be subject to FAA's direction.

Permitting a Broader Reach in NASA Research

In outlining the roles the airlines feel NASA should play in the development of aviation advances, NASA's responsibility to build a technology base through innovative research was listed first. In this task the goal should be to utilize the best scientific minds to create innovations and to enhance our knowledge, with the greatest possible independence of spirit and freedom from bureaucratic entanglement.

While the airlines appreciate the need for a government-conducted, tax-supported research institution to structure its research program so as to project specific output, some research cuts across many disciplines, and talented people should be given freedom to reach broadly across the disciplines toward innovation. It should be possible to earmark a specific significant part of NASA's budget in such a way that such unique effort and far-reaching work can be initiated and supported. One approach may be to permit NASA Center directors to assess such promising broad-reach research efforts and to support them with special funds where the work is clearly of great promise.

The difficulties of administering such funds are great since there is a risk that mediocre talents or ideas will be funded or that research funds will be granted on the basis of existing organizations or staffs rather than merit. Despite these risks, the prospective fruits of such broad reach work are great, and it may be appropriate to form a mechanism by which disinterested experts can contribute their wisdom in judging the prospective value of such research. Perhaps Center directors might use the advice and counsel of such experts (whether they be from industry, Government, or the academic world) chosen in such a way that their advice would be free of any but a scientific stake in the work or its funding.

NASA Research Program Priorities and Emphasis

The joint DOT/NASA Civil Aviation Research and Development (CARD) Policy Study published in March of 1971 noted three major areas of priority work: Noise, Congestion, and a New Shorthaul System. Of the three - by far the most important work area for NASA, in the view of the airlines, is the problem of aircraft noise abatement. The problems of congestion - air traffic control and ground congestion - should be primarily the responsibility of FAA and DOT, although certain aspects should be under the jurisdiction of NASA with guidance from FAA.

With respect to a New Shorthaul System suggested by the CARD study, airlines believe that valuable NASA work done to date shows serious problems of technology, complexity, noise, and cost in the so-called "true" STOL aircraft. The airlines believe that NASA's emphasis should be on technology research in a number of disciplines with which better aircraft and aircraft systems can be built and on the development of improved propulsive lift systems, which can have application across the broad spectrum of transport aircraft including, <u>but not limited to</u>, shorthaul aircraft.

The coordination of effort between DOT, FAA and NASA is critically important and we have seen significant improvement. This coordination is especially important in areas which border on air traffic control. We believe that FAA must have both the authority to conduct air traffic control research and development, and the responsibility for achievement of results. NASA efforts in some aspects of ATC related research can be valuable, in consideration of NASA's capabilities and facilities, but such work should only be undertaken if it is under the overall guidance and direction of FAA.

Airline View on Priorities

In considering the many areas in which NASA can make important contributions to improvements in aviation, air transportation, and aviation safety, it is difficult to establish priorities, since much work can be done in parallel and simultaneously. The following represents a rough priority order which, in the view of the airlines, represents areas in which work is most urgently needed and where fruitful output would be most valuable.

In the later portions of this report relatively detailed recommendations are made in a number of work areas of major concern to the airlines. The following listing is intended as a general priority of effort, and as an indication of funding priority when all efforts cannot be funded fully.

1. Noise Analysis and Abatement

   a. The greatest need for NASA effort and results lies in the area of noise and its abatement. The airlines believe that there is a need for a comprehensive fundamental program of research on the mechanics of noise generation. This work should include efforts in fan noise research, jet noise research, engine machinery noise, the noise mechanisms of aircraft structure (aerodynamic noise), research into the properties and best application of acoustic materials and treatment, and the establishment of a realistically achievable minimum noise level. This work should give important consideration to the practical economics of noise reduction.

   b. The efforts to obtain empirical data to establish the value of new front fans for the JT3D and JT8D should be carried to completion.

   c. There should be a thorough and well-funded program of noise reduction through flight operational procedures. This should have high priority insofar as noise abatement hardware research and development is concerned, since results in this effort can have a relatively early as well as an important impact on the problem.

   d. There should be a comprehensive fundamental program of research into several aspects of psychoacoustics and the relationship of noise annoyance of individuals to ground population distribution and other variables. This effort should include concentration on establishment of better criteria for measurement and description of noise annoyance.

2. Emissions

   A solid and comprehensive program of research on aircraft engine emission and emission control, and establishment of a realistic minimum achievable emission level.

3. Propulsion, Propulsive Lift, and Alternative Energy (Fuel) Sources

   A program of research leading to improved propulsion systems, improved propulsive lift systems, and other

basic propulsion-related efforts such as the development of applications of alternative sources of energy (fuels).

4. A Program of Research in Airframe/Aeronautical Design, Structures, and Materials

   This should be a broad-gauge effort to create a better technology base in airframe and structural design innovation, pursuit of new aeronautical design technologies; and continuation of the traditional NASA program of materials research, with emphasis on lightening, simplification of structures, improvements in fatigue life, and in-service research and evaluation of new materials and structures.

5. Wake Turbulence

   A comprehensive program of research to establish the mechanism of wake vortex turbulence, the physics of formation, life span, and movement of typical wake vortices, and a comprehensive program of research on the elimination of vortices at the source.

6. Aircraft Operational Efficiency and Maintainability Improvements

   This should be a specifically focused multi-disciplinary effort to produce fundamental improvements in the efficiency of aircraft used in the aviation system with particular emphasis on work to reduce the cost of operations and improve the performance of aircraft used particularly in air transportation. In this effort there should be work in aircraft optimization for operation in the existing and the prospective Air Traffic Control system, system design from a maintenance perspective, etc.

7. Flight Control Avionics and System Integrity Research

   A research program in avionics and flight control systems, concentrating predominantly on application of active controls as a means for airframe design simplification, studies leading to better stability augmentation systems, innovative approaches to reliability and fault survival, applications of new avionics systems and display systems to perform unique terminal and approach maneuvers, activities in clear air turbulence detection, etc.

8. Human Factors and Psychoacoustics

   Research in life sciences with particular emphasis on physiological factors related to pilot assessment of

outside visual cues in relation to other aircraft and landing information, physiological factors which may lead to new or improved display systems, investigation of the optimum pilot role in automatic and semi-automatic flight control and air traffic control systems, studies of optimum pilot attention and awareness techniques, and optimum relationships between simulation vs. flight training realism. The psycho-acoustics effort mentioned in 1. above should be encompassed in this discipline.

Detailed Recommendations on NASA Research and Development

1. Noise Analysis and Abatement

a. Fan Noise and Efficiency Research

1) The airlines support the continued development of new front fans for JT8D engines, and continued effort to establish the benefits of new front-fan development for the JT3D engine. This work should continue so as to establish, in realistic terms, the prospective results from such modified engines.

Data from these programs on a) achievable noise reduction, b) degradation or improvement in aircraft performance and engine efficiency, and c) relationship of new front-fan implementation to nacelle acoustic treatment, should then be examined from the standpoints of economic viability and prospects for meaningful reduction of noise annoyance as perceived by airport neighbors. (See also b. and d.)

2) Research to establish the value of single stage high speed (1.7 to 1.9 pressure ratio) fans.

3) Research to establish capabilities of two-stage low speed high pressure ratio (1.9 to 2.5) fans.

4) Assessment of possible advantages of variable-pitch fans at different bypass ratios.

5) Research an optimum inlet - plus - fan aero-dynamic design integration.

6) As a longer term effort, research to establish the capabilities of low speed, low pressure ratio, single stage fans (1.1 to 1.3), including variable pitch fan effects.

7) As longer term research, a study to establish the capabilities of multi-stage fans of very high pressure ratio (1.9 to 3.0) for STOL and SST applications.

b. Jet Noise Research

1) Research to establish the capabilities of the low speed jet (700 ft. to 1500 ft. per second).

2) Research to determine effects of -- turbine swirl, clearance, tip speed, nozzle configuration, mixing suppressors.

3) Research to establish capabilities of coaxial jets: noise behavior of a coaxial jet system at normal climb speeds, including effects of flow disturbances in the mixing zone between the jets.

4) As longer term research, establish the capabilities of high speed jets (1500 feet per second to 3000 feet per second).

5) Establish the capabilities of low speed jets (500 feet to 700 feet per second).

6) As longer term research, basic combustor/duct burning and after burning characteristics. Research in acoustic materials to establish optimum materials for engine noise suppression.

c. As longer term effort, research to establish minimum practical aircraft noise level due to flaps and gear protuberances, vortex turbulence, etc.

d. Research on determination and prediction of a minimum practical propulsion system noise level.

e. Research on the effects of inlet shape and variable geometry effects on noise including the effects of 1) sonic inlets, 2) engine position for minimum noise, 3) retractable splitters, 4) variable lip/suck-in doors.

f. Structural research on advanced load-carrying acoustic treatment materials.

g. Psychoacoustics

1) Spectral shaping as an approach to reducing psychological reaction to noise.

2) Effect of low velocity noise and house vibrations/resonance on annoyance.

3) The relationship of annoyance to demographic (social and economic) variables.

4) Continued research to develop a subjective noise unit, quantifiable in measurable physical terms as a predictor of human response to noise.

5) Research on the effect of thrust reverser noise and control techniques on community annoyance.

6) Validation of current slant range noise levels (beyond 3,000 feet up to at least 20,000 - 30,000 feet) to establish baseline footprints of existing aircraft (as a joint project with FAA).

h. Noise reduction through flight operational procedures (program should be conducted jointly with FAA).

1) Validation of realism and effects of aircraft procedures including effects of psychoacoustic reaction and fear of crash by people on the ground.

2) Validation and establishment of criteria for two-segment, multi-segment, or curved aircraft approach systems, as well as continued search for alternative methods of achieving noise reduction by procedure (such as reduced flap approach procedures) and application of selected techniques to typical aircraft.

3) A research program aimed at reducing takeoffs noise through new or improved procedures. Examples of such research could encompass 0° flap takeoffs (which could lead to a requirement for improved tires and to recertification of most existing aircraft) and automatic programmed flap reduction to achieve noise reduction on takeoff.

2. <u>Emissions</u>

a. Demonstrate combustors meeting the goals specified for the NASA Advanced Technology Transport (ATT) activity for smoke, carbon monoxide, nitrous oxide, and hydrocarbon emission levels in current high by-pass engines.

b. Validate effects of water injection on nitrous oxide formation on various engines, and demonstrate effects on and of other emissions.

c. Develop and demonstrate advanced combustor system for nitrous oxide control on appropriate real engines capable of reducing nitrous oxide by one half by 1975, without water.

d. Conduct research to establish value of two-stage combustor processes, and water injection effects on jet engine emissions.

e. Develop and demonstrate advanced combustion systems capable of reaching ATT goals (by 1979).

f. Review and investigate dispersion of pollutants from aircraft engines in the upper atmosphere. This effort should be a part of broader NASA atmospheric pollution studies, such as the Global Air Pollution Sampling program, which should emphasize the overall environmental goals of the nation.

3. Propulsion, Propulsive Lift, and Alternative Energy (Fuel) Sources

a. Research into economics of gas turbine engine/propulsion systems. Undertake a research effort to establish the cost benefit relationship of various engine design features as a guide to producing economically and environmentally attractive propulsion systems. Such a program should be started forthwith to insure better guidance than the current ATA methods for assessing engine design features. It should address the following:

1) Maintainability criteria and design requirements.

2) Reliability criteria and design requirements.

3) Fuel consumption, purchase cost and maintenance cost relationships and trade-offs.

4) Cost for development, certification and production and minimization (realism of certification testing requirements).

5) Advanced engine diagnostics, including better instrumentation.

b. Advanced Turbines - Longer Term Research

1) Research to establish optimum characteristics for highly loaded high speed turbines (reduced cost of high pressure turbine modules).

2) Highly loaded low speed turbines (reduce cost of low speed fan turbine).

3) Turbine Materials -- improved life, higher temperature, lower cost.

4) Burst protection.

c. Integrated Nacelle Design & Aerodynamics - Near Term Research

Research to establish optimum characteristics for:

1) Weight reduction and improved economics.

2) Validate drag and performance of high speed nacelle configurations.

3) Economic utilization of material for acoustic treatment.

4) Maximize maintainability.

5) Improve engine and reverser design techniques.

d. Advanced Engine Control & Instrumentation - Near Term Research

1) Development of more rugged, reliable and accurate instrumentation for engine operation (pressure, temperature, vibration) and diagnosis of engine faults, including investigation of computer software techniques for performing aircraft engine diagnosis and diagnoses of other complex airborne systems.

2) Development of engine controls which will provide desired required power at fixed power lever angle during appropriate flight segment.

3) Research into development of simpler, more meaningful cockpit displays of engine performance parameters, and a search for improved fuel quantity sensing systems which would avoid problems of electrical noise and contaminants.

e. **Advanced Compressors/Fans**

1) Research into lower cost compressors/fans with high stage loading, fewer blades -- for pressure ratios of 20 to 30.

2) Composite materials.

3) Burst protection.

4) Low deterioration of performance and stall margins.

5) Research into possible applications of advanced technology airfoils to rotating compressors, such as investigation of super-critical airfoils for compressor and turbine blading to achieve lighter and higher-performance rotary.

f. Research to create more efficient, quieter propulsive lift, covering the range of aircraft from conventional to reduced takeoff and landing aircraft, toward achievement of quiet economical so-called "true" STOL operation. The goals for "true STOL" aircraft are so challenging that to pursue the work with less than adequate tools would be false economy. With respect to a "QUESTOL" research vehicle, the airlines support NASA's view that current research vehicles do not have the versatility to make them suitable as test beds for solving the vexing problems which face quiet propulsive lift vehicles, and thus support a NASA research aircraft to perform the needed research in a timely and practical manner.

g. Research Into New Fuels

An energetic research effort to cover all critical aspects of the search for new, unique fuels and the propulsion systems which might utilize them, as a longer term replacement for current fuels.

4. <u>Airframe/Aeronautical Design, Structures, and Materials</u>

a. Research to achieve improved landing and stopping performance by use of non-runway dependent systems such as air-cushion landing systems or reversible fans.

b. Supercritical wing technology should be tested and developed as it might apply to commercial aircraft configurations, including full scale research on low-wing aircraft to assess interference effects, ground effects, etc.

38-266 O - 74 - 14

c. The traditional NASA program on materials research and development should proceed with emphasis on prospective lightening and simplification of structure, and in-service evaluation of reliability and maintainability of new structural materials and structures.

   This effort should include emphasis on development of new coating and plating processes, and inspection techniques, for restoration of surfaces that have deteriorated in normal service.

d. Research and trade-off studies should continue on the use of stability augmentation systems (SAS) to augment the unstabilizing effect of super-critical wing technology, and on the use of full-time active stabilization systems in terms of their impact on simplification and lightening of aircraft structure.

e. A research effort to establish the capabilities of variable geometry aircraft for transport applications. This program should include the study of optimum economics of the subsonic/supersonic mode of operation to help deal with the prospects of eliminating overland booms in supersonic aircraft.

f. With respect to STOL and VTOL aircraft, research should emphasize the establishment of a framework of an "economic criterion of design." Since past NASA work has focused attention on a series of technology problems, such a design criterion would be helpful in assessing the value of future research into STOL and VTOL aircraft.

5. Wake Turbulence

   a. A high priority effort to establish the characteristics of wake vortices, their life cycle, deterioration mechanism, and movement with the passage of time and under varying meteorological conditions.

   b. Research into the causes of wake vortex creation and study of methods of reducing or modifying wake vortices on existing aircraft with minimum modifications of the aircraft, and minimum reduction in efficiency.

   c. Research into more drastic means for ameliorating or eliminating wake vortices from existing and future planned aircraft.

d. Research into the optimum methods for following aircraft to avoid harmful effects from wakes in the path.

e. Close cooperative effort with FAA in the development of wake vortex detection and warning systems.

6. Aircraft Operational Efficiency Improvements

This should be a specifically focused multi-disciplinary effort to produce fundamental improvements in the efficiency of aircraft in the aviation system, with emphasis on work to reduce cost of operation and improve performance of aircraft, especially those used in air transportation. This should be a specifically designated program task for NASA. Useful results would yield valuable advantages to U. S. industry and the international competitive market, as well as offering advantages to all who use air transportation.

A part of NASA's efforts should be to identify areas where promising work should be done. The following should be specifically considered:

a. Research efforts on the improvement of tire life, integrity, and of the entire tire/braking system.

b. Research towards providing better traction under adverse runway conditions and to prevent hydroplaning.

c. Research into improvements in tread and carcass design, as well as tire test methods.

d. Research into materials used in runway surfacing to overcome slippery runway problems as well as research into better ways of removing ice and snow. (This work should be done in cooperation with FAA.)

e. Research into the development of evacuation and escape systems significantly more dependable and safer than those currently in use.

f. Research into system design from a maintainability perspective. This should not be simply a design improvement effort but a broad-based examination of the aircraft systems including materials, structures, avionics, accessories, engines, and other hardware, to determine whether there are better ways of integrating aircraft systems to permit simpler, more maintainable transport vehicles.

g. Research into improved methods of locating aircraft downed in deep water, as well as research on optimum ditching techniques using aircraft models.

h. Research on vehicle optimization for operation in the existing and prospective Air Traffic Control system, starting with the problem of optimizing passenger and/or freight-through-put at given airports of limited acreage.

Research to establish changes and improvements which can be made to aircraft operation to permit a simpler, more efficient air traffic control process. In any such work, the basic guidance and direction should be provided by FAA, and criteria provided by FAA on the prospective characteristics of the Air Traffic Control system, and areas in which vehicle improvements would pay off.

7. Flight Control Avionics and Integrity Research

a. Research into the application of active controls, and the potential application of "fly-by-wire" systems, as a means of airframe design simplification, with particular emphasis on innovative approaches to reliability and fault survival.

b. Research in flight control systems leading to better and simpler stability augmentation systems, ride comfort systems, and simplification of automatic flight control designs. Basic research (as opposed to system design refinement) for the achievement of new orders of reliability, fault survival, and system integrity in full time stability augmentation and flight control systems.

c. Research into the applications of new avionics and displays to permit simple pilot/aircraft performance of unique terminal, approach, and departure procedures (in concert with FAA Air Traffic Control system improvements). This effort should be based on FAA statements of criteria on expected and desired characteristics of future airports.

d. Continuing research into simpler and more effective methods of clear air turbulence detection and clear air turbulence warning systems.

8. Human Factors and Psychoacoustics

This research effort in life sciences should place particular emphasis on physiological factors related to pilots:

a. Assessment of limitations of outside visual cues in permitting pilots to see other aircraft and in landing;

b. establishment of physiological factors which may lead to new or improved display systems;

c. establishment of pilot factors to aid in determining optimum pilot role in automatic and semi-automatic flight control and Air Traffic Control systems;

d. studies of optimum pilot attention and awareness techniques;

e. optimum relationships between simulation and flight training in terms of training realism; and

f. continued research into better and simpler pilot training devices.

9. Additional Research Recommendations

a. Research and development toward achievement of an insecticide which can be dispensed through normal aircraft air conditioning distribution systems during taxi-out. Such insecticide must be compatible with all aircraft materials, and be non-hazardous to humans (infant and adult), live cargo, or agricultural materials.

b. Research into advanced filtration systems for control of odors and contaminants which enter the cabin through the air conditioning system, particularly during extending ground holding periods prior to take-off.

c. Research and development into improved heat transfer methods for discrete electronic units, and studies into reliability and life improvement for electronic systems under various conditions of environmental control.

d. Research and development into improved hydraulic fluids. There is need for work on a fire-resistant fluid with fewer undesirable side

effects, improved metal erosion characteristics, higher thermal stability, and lower solvency activity, than current fluids.

e. Ozone data collection and studies of the effect of ozone on aircraft materials for consideration of future SST designs.

Other NASA Research Areas

In addition to the above nine categories of research, the airlines support NASA research efforts in basic satellite technology as they may lead to improved communications and (subsequently) ranging capabilities. Such work should be done under the direction and guidance of FAA.

Airlines see relatively little prospective benefit for civil transport operations, especially in the nearer term, in such efforts as VTOL or tilt rotor research, nor research on hypersonic transport vehicles.

The airlines support further work in the basic technologies of supersonic flight in order to maintain an acceptable U. S. base for this technology.

Statement of: Arthur G. Crimmins
Manager
Aerocrane Programs
All American Engineering Company
Wilmington, Del. 19899

Mr. Chairman:

We very much appreciate the opportunity to comment on the efforts being made to expand man's overall ability to lift and move heavy loads. The fact of these hearings indicate that the basic thinking is being done, that is so vital if we are to solve old problems in a new way.

As a point of beginning, let us assume that some form of aerial device could operate like a helicopter but, instead of only being able to lift 12 tons as is the case with the largest available helicopter, let us imagine a capability of up to 1000 tons. Also let us assume that this new aerial device will operate at a cost factor between 10 and 20% of helicopter costs per pound of lift. Without attempting to define the mechanical details of this device, which I shall call the "Aerocrane", let us think of the services that such an aerial vehicle could perform.

In the industrial nations of the world the postulated Aerocrane could build bridges, aid in industrial plant construction, assist in agriculture in many ways from pest control to timber harvesting and greatly aid the construction of energy generating facilities. Perhaps the major use would be in the delivery of highly desirable dwelling units from "house factories" that could apply the incredibly successful mass production techniques of industry to our housing problem.

The ability of the Aerocrane to vertically lift loads as large as virtually any land based crane without the need for roads or ground preparation of any sort will be useful in many cases.

Even in such rather mundane areas such as earth moving, the Aerocrane could give access to natural resources such as coal, oil shale, and timber now considered economically inaccessible. In this use the proposed aerial vehicle would be fitted with a clam bucket and overburden removed (and spread over previously mined areas for ease of land reclamation) and/or ore loaded into trucks for transport.

In the Less Developed Countries (LDC) the Aerocrane could literally mean instant prosperity by making available vast quantities of raw materials without the need for the staggering investments now required in roads and rail systems. In a world plagued by shortages and high raw material prices engineered by short-sighted policy decisions of a few nations fortunate enough to have readily accessible resources, the advent of the postulated Aerocrane would break most raw material monopolies by suddenly bringing new suppliers into the market where the law of supply and demand would again be operative.

A major use for such an Aerocrane would be in the unloading of cargo from containerships. A 90-ton slingload Aerocrane could provide a highly cost effective method of containership unloading for both civilian and military needs.

As the need for logistic support is the backbone of any military operation, a highly versatile crane such as we postulate would soon be indispensable, particularly as the merchant marine fleets of the world become more and more a container moving system.

There seems to be little doubt that if such an "Aerocrane" existed as an American product, the export sales alone would quickly be a major factor in our balance of payments, particularly if such a device used a major natural resource, such as helium, in quantity.

It is my pleasure to assure you and the members of this committee that a flying model of such a device is alive and well and living at All American Engineering Company in Wilmington, Delaware.

The All American Aerocrane concept has been examined by the Aerospace Corporation of El Segundo, California under contract from the U.S. Forest Service with the opinion expressed that the Aerocrane is feasible, well within the state of the art and potentially a highly useful and cost effective vehicle, not only for timber harvestry but for many other uses.

A U. S. Navy contract has just been completed that has firmly established that the validity of the Aerocrane concept is fully supported by extensive analytical work proving, among other points, that the Aerocrane is remarkably insensitive to structural weight relationships. In fact, the structural weight of the Aerocrane can actually be equal to the total aerodynamic lift (a situation that would absolutely prevent true flight in a helicopter or airplane) with less than a 15% effect on overall performance.

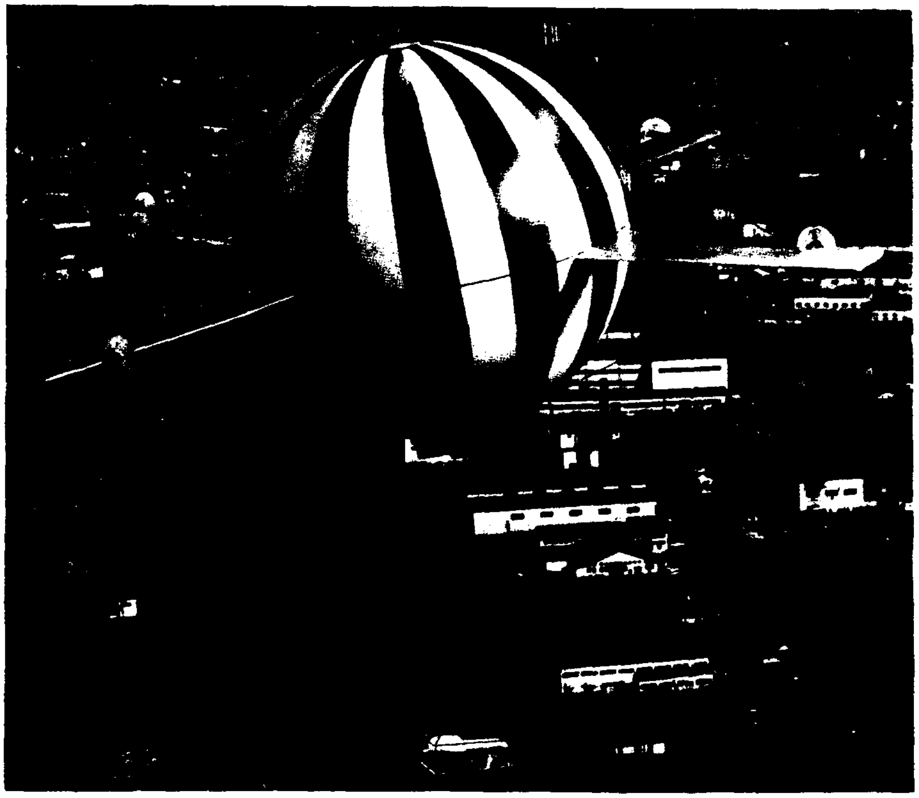
A brief description of the Aerocrane is attached.

We are in the beginning phase of the development program needed. The Naval Air Systems Command, Advanced Concepts Division has had program management responsibility for the first contract. The Surface Container System division of the Army Material Council has shown interest in the Aerocrane as a vital link in containership off loading in support of military operations.

We feel the final requirement is a full appreciation by Congress of the need for and feasibility of the Aerocrane concept. We would welcome the opportunity to demonstrate the 33 foot wing span flying model now operational in Wilmington, Delaware.

THE AEROCRANE

A NEW CONCEPT IN ULTRA HEAVY VERTICAL LIFT



ALL AMERICAN ENGINEERING COMPANY
a subsidiary of ALL AMERICAN INDUSTRIES, INC.
BOX 1247 • 801 SOUTH MADISON STREET • WILMINGTON, DELAWARE • 19899 • PHONE 302-654-6131
TWX 510-666-3657 CABLE ALAMEN

Combination Lines H.T.

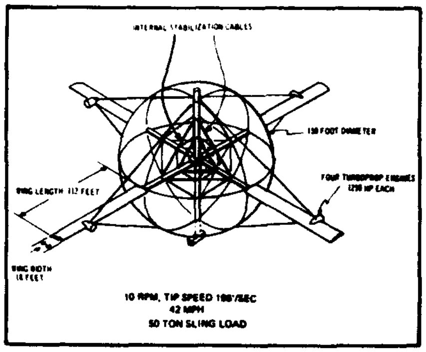


Figure 1

The low wing loading resulting from the low relative wind velocities and the external wing cable supports permits uncomplicated construction techniques, much different than either high-speed fixed-wing or conventional rotary-wing aircraft. Because of the buoyance of the Aerocrane, structural weight is also less important relative to present powered aircraft and therefore permits lower cost and longer life component design while maintaining a high operating efficiency and low cost operation.

Because of varying lift requirements and the necessity of vertical and horizontal directional and rate control, the wings will require both cyclic and collective pitch control. This will be accomplished from either a mechanical or combination mechanical/aerodynamic control system.

The wings will be attached to the spheroid at the equatorial plane through pivotal connections to the tubular spars which converge at the centroid of the sphere.

Description of a Fifty-Ton Slingload Aerocrane

Figure 1 shows a conceptual Aerocrane with four 112-foot long by 18-foot wide wings, each having a turbo prop power plant mounted on a 150-foot diameter spheroid.

Also shown in the figure is one possible approach to the design of the skeletal structure internal to the spheroid: a light-weight concept having tubular wing spars extending from a central point within the spheroid with another tube extending through the vertical axis down to the control cab. A matrix of cables interconnecting these tubes completes this uncomplicated but efficient primary structure.

Aerostat

The aerostatic portion of the Aerocrane is sized to achieve sufficient buoyance to lift the total vehicle weight, including fuel, plus buoyancy of up to 50 percent of the slingload (in this case 50,000 pounds).

The 150-foot diameter spheroid is constructed of a membrane covering the primary tube and cable structure.

Wings and Powerplants

The aerostatic lift is supplemented by aerodynamic lift generated by rotating the entire spheroid/wing assembly at a low speed (approximately 10 RPM). The aerodynamic lift provided by the wings is 50 percent of the slingload (50,000 pounds). The rotor thrust is vectorable and is used to maneuver and propel the Aerocrane.

An estimated (maximum) 1500 horsepower turbo prop powerplant on each of four wings will provide the power necessary to lift a 50-ton slingload and translate at 42 mph.

Control Cab

A control cab or gondola from which the Aerocrane will be piloted is located directly below the vertical centerline of the spheroid.

This gondola must be adequate to provide all the necessary engine and flight controls, navigation equipment, radio equipment and life support functions dictated by the mission requirements.

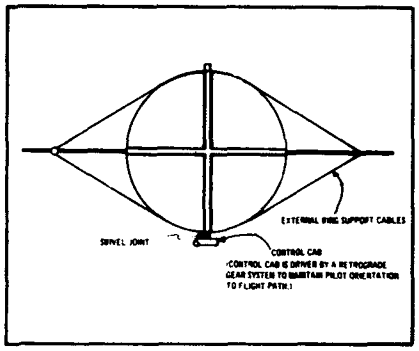


Figure 2

To provide positive orientation of the control cab and prevent rotation with the spheroid, there is a swiveling joint above the cab and a retrograde drive system (see Figure 2).

<u>Performance</u>

The Aerocrane adds a totally new dimension to the performance of air vehicles with respect to payload capability, vehicle cost per pound of payload and operating cost.

While the Aerocrane is inherently limited to relatively low translational speeds because of the high parasitic drag of its aerostatic sphere and normal slingloads, it has high efficiency over most normal wind conditions at the low altitudes in which it will normally operate.

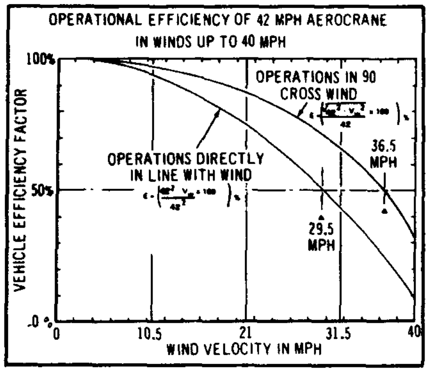


Figure 3

Figure 3 is a plot of vehicle time efficiency at different wind speeds for a 42 mph Aerocrane. In this case vehicle time efficiency is the ratio of time under no wind conditions to cover one nautical miles to the average time to cover one nautical mile in each direction under ambient wind conditions. Note that is winds up to approximately 30 mph, efficiencies of over 50 percent result over any closed course.

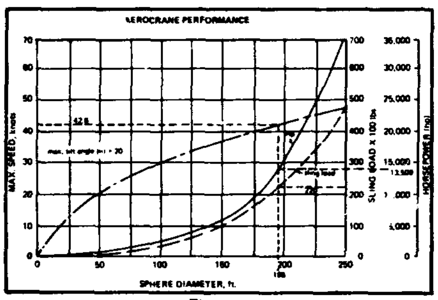


Figure 4

In contrast to the traditional penalties for scaling up a conventional rotary wing aircraft, the Aerocrane becomes more attractive in larger sizes. Figure 4 shows the approximate scaling effects on the Aerocrane. Note that an Aerocrane capable of lifting 220,000 pounds would have a sphere diameter of 195 feet (only 45 feet larger than one for 100,000 pounds) and require a total horsepower of about 13,500 to translate at 42 knots.

Another attractive feature of Aerocrane lies in its overload capability. A vertical lift overload of about 20 tons is possible; translational speed capability, however, will be reduced. In other words, if structurally designed to resist the 20-ton overloads, the 50-ton Aerocrane would be able to lift 70 tons, but translate at 25 K.

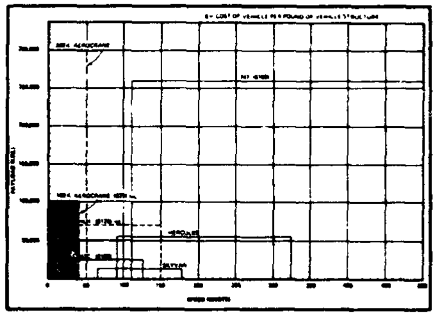


Figure 5

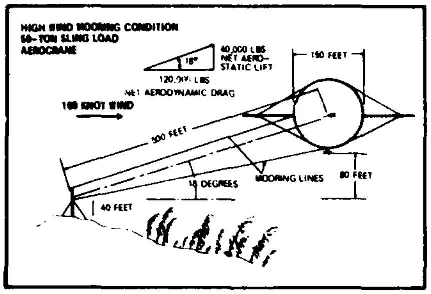
Vehicle purchase cost relative to payload capacity is another important performance consideration. For example, each pound of payload capacity in a CH-47C helicopter costs about \$100, or about the same as a Boeing 747. An Aerocrane, on the other hand, is estimated to cost about \$25 per pound of slingload regardless of its size. Figure 5 compares representative fixed- and rotary-wing aircraft payloads, costs and speeds to Aerocranes of 50- and 150-ton slingload capacities.

<u>Control System</u>

Although it may prove possible to use normal helicopter type cyclic and collective pitch control for the Aerocrane, the rigid non-flapping wings may transmit unacceptable cyclic loadings to the structure resulting in a wallowing action would could cause crew discomfort. Preliminary calculations have shown also that quite high aerodynamic gust and maneuvering loads are possible if the relieving effect of blade flap is not present.

One promising approach is a control system in which the wings are pivoted well ahead of their aerodynamic center and torque of known amounts is collectively and cyclically applied to induce the required thrust from each blade. The problem of phase lag due to a change in moment not giving an immediate change in thrust must be carefully considered.

The use of aerodynamic (tab or elevator) control as well as direct root control will be considered.



MOORING

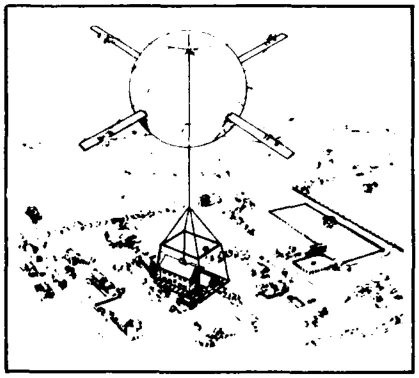
Mooring

Becuase of the high reserve buoyancy to drag ratio inherent in a large Aerocrane, mooring under high winds appears feasible.

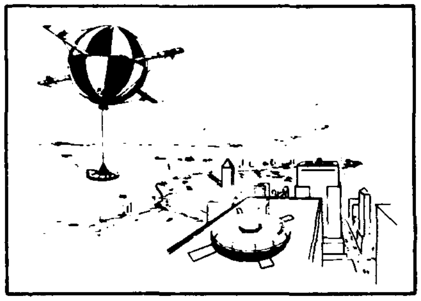
Figure 6 shows a possible two line mooring configuration for a 50-ton slingload Aerocrane in well above hurricane force wind conditions (100 knots). Note that the 1:3 net lift-to-drag ratio give 80 feet of vertical ground clearance above the ground tether point with approximately 500 feet of mooring line length.

This is a purely static approach to a highly dynamic situation and is not intended to indicate that a vehicle of this size can be successfully moored under the : conditions. Until satisfactory mooring systems can be analy :d and tested, a vehicle of this type will be better in flight during unusual wind conditions.

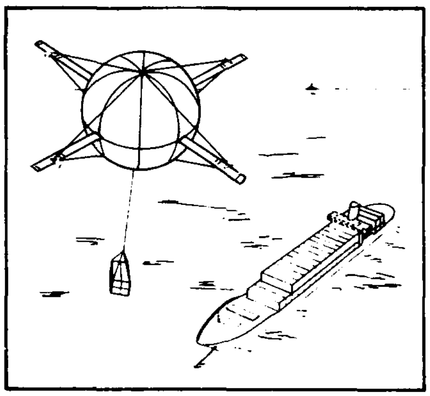
Many potential uses have been suggested. The cover illustrates a nuclear generating plant component weighing 500 tons being transported by an Aerocrane. The following illustrations point out a few more suggested uses.



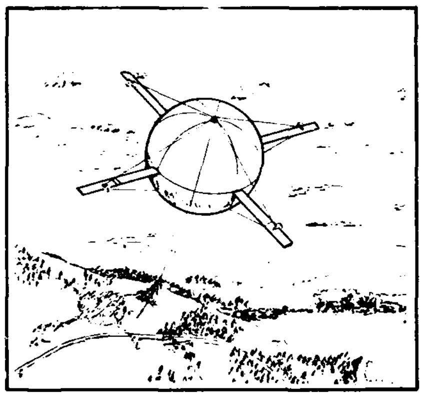
FACTORY-BUILT HOME DELIVERY



MASS TRANSPORTATION



CONTAINER SHIP UNLOADING



WHOLE TREE AERIAL LOGGING

4-5-7 (M)

AMERICAN HELICOPTER SOCIETY, INC.

30 East 42nd Street • New York, N. Y. 10017
Tel.: Area Code 212-697-5168

9 July 1974

The Honorable Frank E. Moss
Chairman, Committee on
Aeronautical and Space Sciences
United States Senate
Washington, D. C. 20510

Dear Senator Moss:

It has been brought to my attention that your Committee on Aeronautical and Space Sciences will hold hearings this month to investigate new ideas for aircraft of the 1980's and beyond. Let me urge that your considerations include the future role of the light helicopter, particularly in urban transport.

Enclosed is a copy of a paper presented by me to the Helicopter Association of America at an annual meeting of its full membership. It would be appreciated if you will include it as part of your hearing record, along with this letter.

To summarize the paper, we in the helicopter industry believe that by the 1980's the helicopter will become to intracity transportation what fixed-wing aircraft have been to intercity transportation for the past 30 years. With increased urban surface congestion, higher costs of rights-of-way and continued decentralization of metropolitan areas, local commerce and industry will need a transportation system that requires a relatively small investment, uses a minimum of land and offers the potential of speed, low cost, low noise, safety, convenience and comfort. The solution to these requirements is within the realm of existing helicopter technology.

I believe that the enclosed paper substantiates this fully. If further details or documentation is desired, please feel free to call on me.

Sincerely yours,

T. R. Stuelpnagel
President

Encl/as noted

THOMAS R. STUELPNAGEL
VICE PRESIDENT AND
GENERAL MANAGER

HUGHES HELICOPTERS
DIVISION OF SUMMA CORP.

(213) 870-3061
CENTINELA & TEALE STREETS
CULVER CITY, CALIFORNIA

The Helicopter is a Necessary Urban Transport for the 1980's

Thomas R. Stuelpnagel
Vice President and General Manager
Hughes Helicopter Company

THE HELICOPTER IS A NECESSARY URBAN TRANSPORT FOR THE 1980's

It is well known that the economic growth of an urban community is dependent upon mobility within the community. The question posed in this study is whether this mobility can be achieved without the operation of an urban VTOL transport.

It is contended that a sound economic growth of the urban community will require the use of helicopter transports in the 1980's. Further, it is believed that the helicopter will be to intra city transportation in the next 30 years what fixed wing aircraft have been to inter city transportation in the last 30 years.

Air transportation has been the lifeline to national economic growth. It will have the same dramatic impact on the future economic growth of our urban areas. The difference is that the distances involved in the urban community are typically 20 times shorter. As such, the air vehicle involved will be different but the job will be the same.

The urban transportation problem has resulted in great emphasis being placed on the development and modernization of mass transit for improved mobility in the growing urban areas. This effort is properly looked upon as an important solution to moving a large number of people in the shortest period of time. However, there is an inclination of many planners to look upon surface rapid transit as a panacea for resolving the entire needs of the urban communities to the exclusion of alternate transportation modes, such as air transport for special transport requirements. This position is unsound and needs to be changed for several reasons. First, it can be shown that the urban population and employment growth has been occurring at a more rapid rate in the metropolitan rings than in the central cities now serviced by rapid transit systems. Second, this decentralization of urban areas increases the cost of the surface transportation systems because of the exponential growth in area or increased line haul miles and the increased equipment needs to provide the service. Third, the economic requirements of urban decentralization can be correlated with national economic growth that was accompanied by the growth of air transportation and stems from the importance of time saving as travel distances increase. Fourth, the helicopter transport is a practical solution to meeting urban economic development requirements. It is practical in terms of cost, speed, noise, safety, convenience and land requirements, being at a development and operational stage similar to that preceding the large scale introduction of the DC-3. The technology is now ready to be effectively exploited for the benefit of special urban transportation requirements.

These reasons dictate the need for the development of a helicopter urban transport in conjunction with other modes of transportation. Let us examine each of these reasons more carefully.

URBAN GROWTH

As urban population has grown, it has been accompanied by a greater increase of people living outside central cities than in central cities, as shown in Figure 1, with projections to 1985.

In addition, this pattern is also reflected in a significantly greater rise in total employment outside of central cities as compared to the central cities, Figure 2. These patterns reflect a clear decentralisation of business and population around metropolitan areas and a resultant increase in distance between many companies doing business with each other in these areas. In this decentralisation picture, it is also found[1] that transit usage does not stem the tide of decentralisation of population and employment from the central city. In fact, it has been found that central cities with the highest transit usage consistently exhibit the smallest increases or the largest declines in employment and population in both their central cities and metropolitan rings. Yet, in this decentralisation movement, massive emphasis is being put on rapid transit servicing central cities to the exclusion of alternate modes of transportation that could provide rapid service between business enterprises in the metropolitan rings.

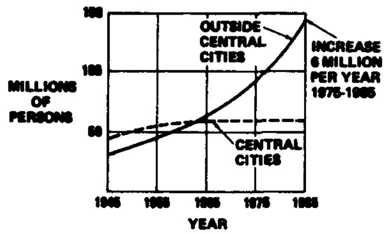


Figure 1. Urban Population Growth*

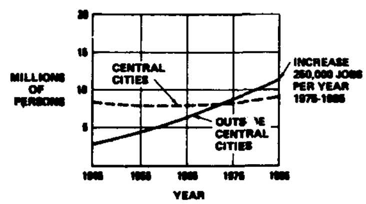


Figure 2. Total Employment for the 24 Largest Cities in Manufacturing, Trade and Selected Services*

*Source: A. Gans, "Emerging Patterns of Urban Growth and Travel," MIT, Project Transportation

[1] Meyer, J.R., Kain, J.F., Wohl, M., "The Urban Transportation Problem," Harvard University Press, Cambridge, Mass.

SURFACE TRANSPOR**T**ATION NEEDS

The geometry of the expanding metropolitan radius results in an exponential growth of the area needing transportation service. It follows that this requires a greater investment in rights-of-way for all surface modes and an increase in mileage, facilities, and equipment to provide the needed service. With this expansion of distance, the need for time-saving transportation modes becomes a greater economic necessity.

TRANSPORTATION AND ECONOMIC GROWTH

The need and development of time saving transportation modes was at the forefront of U.S. economic development. This need was manifested in the exponential growth in U.S. commercial air transportation after World War II as shown in Figure 3. Accompanying this growth was an exponential growth in domestic trade as reflected by the revenue for various modes of domestic property shipments shown in Figure 4. This growth in trade correlates with the growth in air travel because the entrepreneurs developing new business made up approximately two-thirds of the total travel, increasing exponentially (per Figure 5), with increased trade.

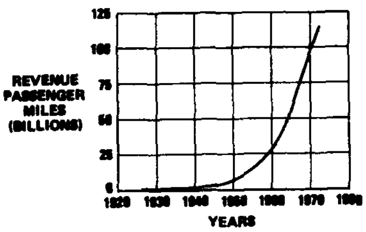


Figure 3. *Domestic Air Travel**

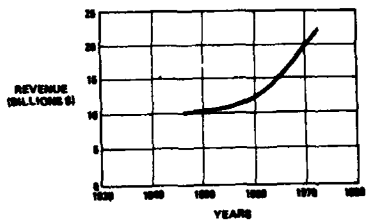


Figure 4. Domestic Shipping Revenue From Motor Carrier, Air and Rail Transportation**

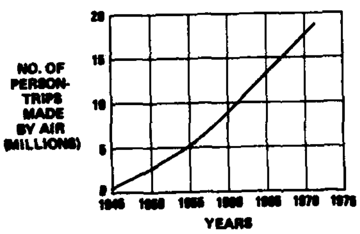


Figure 5. Business Air Travel***

*Source: "Handbook of Airline Statistics" and "Air Carrier Traffice Statistics," Published by CAB.

**Source: "1969 Business Statistics" and "Survey of Current Business," U.S. Department of Commerce.

***Source: "1963 and 1967 Census of Transportation." U.S. Department of Commerce.

38-266 O - 74 - 15

To facilitate this gro\..n in air transportation and eco..mic development, the air transport industry developed the transports with continually increasing capability and reduced cost. This made available the capacity, as shown in Figure 6, and the cost saving to stimulate the growth of air transportation. Of course, these factors were also accompanied by increased service to more cities and airports in all kinds of weather, plus greater safety, comfort and convenience, which is the history of U.S. transport aviation development. However, it must be remembered that this evolution started with the imagination and vision of many great aviation pioneers in industry, airlines and government. They recognized the potential of an unproven system to effect the

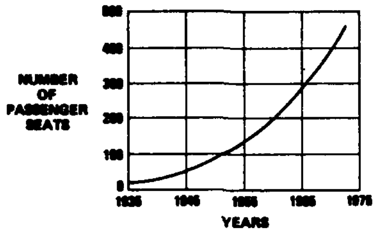


Figure 6. Growth in Fixed Wing Aircraft Size*

*Source: Jane's, "All the World's Aircraft."

kind of time savings at a premium price that eventually became a stimulus for U.S. economic development tying the nation closer together and stimulating the expansion of foreign trade. This same phenomenon applies to the growing urban areas to assure economic development *within specific areas* and between areas. There is a need for air transportation to assure economic viability and growth.

URBAN HELICOPTER TRANSPORTATION

In the 1980 period, we are faced with the following: increased congestion from a growing number of automobiles; the prospect of paying premium cost for rights-of-way; and more equipment for new rapid transit systems to service the metropolitan rings and, in many urban communities, to service the central city. The decentralization of the city amplifies all of these problems as the radius increases and the area goes up exponentially. In this period of increasing distances between urban industrial enterprises doing business together and between enterprises and commercial airports servicing visiting businessmen, there is a growing need for a new transportation system: one that is not impeded by surface congestion, requires a relatively small investment, uses a minimum of premium land, and offers the potential of speed, low cost, low noise, safety, convenience and comfort to an important segment of the traveling public.

The way to achieve th. objective is by introducing a he...opter that is smaller than used to date because of the ability to master the problems and make it economical at this time. The concept proposed is a light twin engine helicopter with a 10-passenger capacity, equipped for IFR, incorporating quieting features capable of reducing noise by 90 percent from that of more conventional designs and providing a structural integrity and safety exceeding any commercial design ever built. This helicopter would provide: average speeds from origin to destination that are three or more times faster than that of surface modes, an operating cost equal to that of a taxicab, great flexibility in route structure, a utility value[2] that now is twice as great as that of a taxicab and could exceed that of a private automobile as the helicopter system was developed to provide lower helicopter maintenance and more helistops.

In support of this solution for intracity transportation, a few facts will be examined. If the helicopter today is compared to the fixed wing aircraft in size, Figure 7, the helicopter is at a point today that fixed wing air transportation was at about the time the DC-3 was making its impact on air transportation growth, approximately 30 years after both their inception.

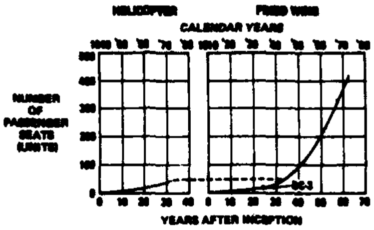


Figure 7. Transport Aircraft Size Comparison*

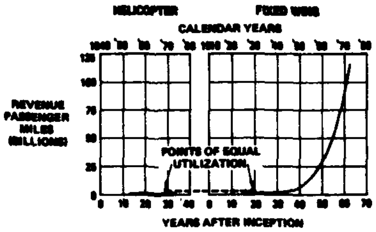


Figure 8. Transport Aircraft Utilization**

*Source: Jane's, "All the World's Aircraft."
**Source: "Handbook of Airline Statisitcs," CAB.

2 Utility Value = $\frac{\text{Passenger Volume x Average Speed}}{\text{Total Cost}}$

However, a comparison of helicopter and fixed wing utilisation, Figure 8, indicates that the helicopter has fallen behind by approximately ten years. This is due to the lack of community acceptance resulting from helicopter noise, reliability deficiencies, high cost and proximity of operations to residential and business establishments. In more recent times this problem has worsened as evidenced by the decline in helicopter airline operations shown in Figure 9.

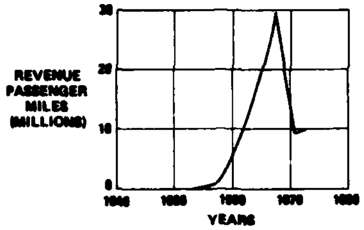


Figure 9. Helicopter Transport Utilisation*

*Source: "Handbook of Airline Statistics," CAB.

Therefore, what is needed is a helicopter of the type previously described for intracity operation that satisfies the low noise and high reliability criteria that would encourage user and community acceptance.

Looking to the future, it is clearly feasible for industry to provide a 10-passenger helicopter operating in a commuter mode between, say, two high traffic density points with a high enough load factor on a 10-minute departure schedule to experience a low cost operation. As in the early days of fixed wing transports, some small subsidy might be required at the outset but it is expected to operate without subsidy and at a profit as the system, equipment, and facilities evolve. Figure 10 depicts the projected cost through the year 2000. Compared to other modes of transportation, the cost can be expected to be competitive in the next 30 years, but the average speed of the helicopter will far exceed that of the surface transport – adding greatly to its utility value for business and economic needs in the megalopolitan area.

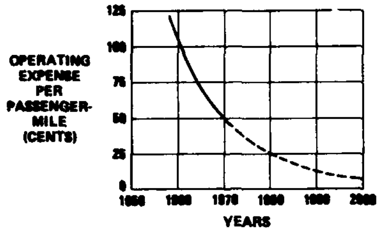


Figure 10. Helicopter Operating Expense**

**Source: "Handbook of Airline Statistics," CAB.

The thesis is that the growth of the helicopter is consonant with the growth of the city. Helicopter utilization is dependent on having a machine that is acceptable by the community to fly over their houses and into conveniently located heliports. The economic and business need already exists when one considers that approximately three million trips under 50 miles are made by air, and half of these are made for business annually. [3]

In addition, the helicopter transportation system will require approximately one-tenth the land needed for STOL aircraft systems and 1/300th the land needed for rail and road transportation serving a 30-mile equivalent route.

Therefore, we find that a helicopter transportation system can be an effective alternative transportation system to alleviate the traffic congestion in urban areas while offering all of the other benefits cited, most important of which is the stimulus for sound economic development.

In view of these facts, we believe it is time for action to assure balanced transportation development. The Transportation Department has assessed[4] that $670 billion will be required for transportation through 1990. Of this, $560 billion will be required for highway construction and $63 billion for public transit needs. Of the latter, 70 percent would be for railways. It is proposed that approximately 1 percent of the public transit funds or approximately $500 million be used to develop a helicopter transportation system for 25 major cities over the next 20 years. The money would be disbursed as follows: $100 million for a helicopter development program that could be paid back from royalties on helicopter sales; $250 million for ten terminals to begin with in each of 25 major metropolitan areas; $50 million for air traffic control facilities; and $100 million for personnel training, administration, and general expenses.

This investment will support the next major economic growth in the United States that will take place in the urban areas outside of the central cities, and contribute to the development of better than 250,000 jobs per year in the manufacturing, trade, and selected services outside the 25 central cities. These jobs represent an increase in local income in excess of $100 billion over a 20-year period from 1980 to 2000. This income will have a multiplying effect on national income as well.

Thus, an investment of $500 million helps to create and support an increase of $100 billion in the 20-year economic base of the urban areas outside central cities at a time when there is a growing resistance to extending freeway and railroad rights-of-way that threatens to restrain economic growth.

---

[3] "1967 Census of Transportation, National Travel Survey," U.S. Department of Commerce.

[4] "1972 National Transportation Report," Department of Transportation, July 1972.

The facts presented here warrant an immediate effort to invest money in the development of the basic helicopter and an experimental operation in a selected location. This will permit the early evaluation of the system to establish the costs and operating requirements for national implementation.

The necessity for a helicopter transportation system for urban application is the key to the growth of employment and economic viability of the developing urban communities. A helicopter transportation system must be regarded as a necessary supplement to rail and road development.

381-0711

HUGHES AIRCRAFT COMPANY 4.5-7(M)

CULVER CITY
CALIFORNIA

July 2, 1974

Honorable Frank E. Moss
Chairman, Committee on Aeronautical
and Space Sciences
United States Senate
Washington, D. C. 20510

Dear Chairman Moss:

This is in reply to your letter of June 18 to Mr. L. A. Hyland, our General Manager, in which you offered us the opportunity to submit a statement in connection with your planned hearings on Advanced Aeronautical Concepts.

Our company is not active in any of the areas of engineering which are listed for your agenda. However, we are co-located with Hughes Helicopters. I have taken the liberty of passing your statement on to Mr. T. R. Stuelpnagel, Vice President and General Manager of Hughes Helicopters, thinking that he may be able to submit a statement which may be of interest to you on one of these subjects.

Very truly yours,

L. S. Jerrems
Director of Technology

BOEING COMMERCIAL AIRPLANE COMPANY

P.O. Box 3707
Seattle, Washington 98124

A Division of The Boeing Company

July 25, 1974
B-7210-1-167

Senator Frank E. Moss
Committee on Aeronautical & Space Science
Washington, D.C. 20510

Dear Senator Moss:

Thank you for the opportunity to present written testimony for your hearings on advanced aeronautical concepts. This letter will address three of the five general areas covered by the hearings: new aircraft designs, engines and fuels, and safety. The comments apply primarily to commercial aviation.

Before getting to specific suggestions, I would like to discuss briefly the philosophy of the government industry relationship in maintaining a healthy aircraft industry. This country has been highly successful in a commercial airplane business despite competition from European countries with much lower labor rates than ours. The two principal reasons for our ability to attain high world market penetration have been; a) our technological base together with the ability to translate it into high volume, efficient production, and b) the ability of the U.S. aircraft industry to tailor airplanes to the needs of airlines.

The technological advantage of the U.S. aircraft industry has in large part been a fallout of past military aircraft development. In recent years military research has declined and NASA spending has been primarily on space exploration. Meanwhile, foreign governments have directly subsidized their industries in development of new commercial airplane programs. The most recent examples are the A-300 short-to-medium range passenger airplanes and the Concorde. Despite this trend, we do not expect the government of the United States to spearhead commercial airplane developments. We feel that more flexibility is available to find the right airplane combination for the airline market when the exchange on requirements can take place directly between airline and the manufacturer and when program go-ahead decisions are made on a strictly commercial economics basis. Profit motive is a good decision criterion.

We feel that the principal role of the government should be in pioneering high risk technological research. If the government can spearhead the development of new technology then private industry should be able to capitalize upon that know-how in bringing forth new airplane development programs. The technology needed may not all be developed in the laboratory. In the past, research airplanes such as the X series of airplanes after

BOEING

World War II have proved to be extremely valuable and are reasonably economical for bringing forth and trying out new ideas in aeronautical technology. Some research can be best carried out by government agencies in-house, e.g. development of new airfoil or high lift technology. Other government sponsored research should be contracted to industry, e.g. airplane configuration studies or research aircraft.

In the following paragraphs some general comments will be made in the areas of new aircraft designs, engines and fuels, and safety and examples of worthwhile research projects will be cited.

NEW AIRCRAFT DESIGNS

New commercial airplanes will be required during the 80's and 90's in one or more of the categories of subsonic, supersonic, and transonic passenger airplanes, STOL, and very large airfreighters.

The technology necessary to support medium range subsonic aircraft should emphasize fuel efficiency as well as environmental factors. These aircraft make the most takeoffs and landings and consume the majority of the fuel used in aviation. Research emphasis should include terminal area technology (aircraft and ground systems). This should include technology to improve the aircraft handling capacity of airports and to reduce the fuel that is wasted by delays in takeoffs and landings. Improvements are needed in propulsion systems for conservation of both fuel and the environment. These will be discussed further under Propulsion and Fuels.

There is little doubt that efficient supersonic flight can allow a quantum jump in long range commercial air transport productivity and usefulness. Research is necessary to ensure that such aircraft are not only economically attractive but that environmental questions such as noise can be addressed from a solid technical data base. The military importance of efficient supersonic flight is also self-evident. Despite current shortcomings, the Concorde still is a continuing source of advanced technological data and forms the nucleus around which a first class technology team is being developed. Important fields where the U.S. could develop its own supersonic technology include variable-cycle engines, structural concepts, and configuration integration.

STOL aircraft have important military applications. In the commercial field, as airline traffic grows, new terminals will be required eventually to alleviate congestion. Economics and other land use restrictions will tend to limit space available for airports and the development of STOL may become essential for the orderly development of a good total transportation system. Research is required prior to the design of these STOL aircraft with emphasis in the following areas: Propulsive lift techniques to allow short field performance with minimum sacrifice of flight efficiency;

guidance and control to ensure safe flight at very low flight speeds near the ground; noise reduction schemes to eliminate the adverse impact of engine and airframe noise.

Very large aircraft will provide a unique means of delivering cargo over long distances efficiently and quickly. They may have important commercial and military applications. Technological building blocks are needed as well as formation of engineering teams to integrate the designs. Key technical areas include research on: very thick airfoils; structural load alleviation; structural materials and concepts development to allow lightweight large structures; integrated guidance and control; and active controls to improve airplane efficiency. Research will be necessary also in the area of manufacturing techniques to ensure eventual design and construction of these large aircraft at low cost. Use of laminar flow control to reduce drag and improve energy efficiency should also be re-examined.

PROPULSION AND FUELS

As mentioned earlier, development of improved propulsion systems is probably the single most important advance needed to cope with the fuel shortage and the increased sensitivity of the public to aircraft noise and pollution. Continuing research towards improvements in these areas is very important to the future of commercial aviation. One technology area that has considerable promise is that of variable geometry in engines. The variable geometry may come about from variable components (e.g. compressor blade pitch changes) or from valving that allows changes in bypass ratio. One version of a variable bypass engine has been tested at Pratt & Whitney Aircraft under Air Force contract. This concept could allow great improvements in supersonic aircraft by providing high bypass ratio to provide low noise and high fuel efficiency in the vicinity of the airport. It allows switching to a low bypass ratio for maximum fuel economy in the supersonic portion of the flight.

In the area of fuels, there is a need to establish the characteristics of aircraft-type fuels derived from coal and oil shales. If these characterestics are found to differ significantly from current ones, there should be testing of these fuels in various types of aircraft engines with the objective of finding the right compromise between extraction and refining processes, fuel characteristics acceptable to aviation, and economics. Fossil fuels face eventual exhaustion and long term studies of alternatives are in order. Synthetic hydrocarbons, hydrogen, and nuclear propulsion should be investigated. Synthetic hydrocarbons here refers to hydrocarbon fuels made from non-fossil materials. While hydrogen suffers from low energy per unit of volume and current high cost, it has very high energy content per pound and would be compatible with airplanes of the future, including hypersonic airplanes. Also, in the longer term, improvements in core design and shielding may eventually make nuclear propulsion economical for large airplanes.

SAFETY

Commercial air travel is currently one of the safest modes of transportation. Fatalities per passenger mile are lower than those for automobiles by a factor of six. However, further efforts and research to improve aircraft safety are considered very important. Many of the improvements in other technologies such as propulsion and structures and flight controls will reflect themselves in improved reliability and safety. Specific areas where more research seems to be needed are: crew factors, weather forecasting, and crashworthiness.

Crew-factor research is desirable to find ways to help the flight crew perform their duties through improved human engineering or better training procedures. Research on improved weather forecasts and reporting should cover clear air turbulence avoidance, runway visual range, and improved current weather reporting. Research to improve airplane crashworthiness should include development of fire resistant materials and research on improved structural integrity of airplanes in crashes.

The above comments are not meant to be all inclusive but to give examples of areas where increased research could be sponsored by the U.S. government.

Very truly yours,

H. W. Withington
Vice President - Engineering

BOEING

_(4.5-7(m)

COMBUSTION DIVISION, COMBUSTION ENGINEERING, INC
WINDSOR, CONN. 06095
203-688-1911 CABLE: COMBENG

COMBUSTION DIVISION

July 8, 1974
PSP-74-185

Mr. Charles F. Lombard, Minority Counsel
Committee on Aeronautical and Space Sciences
Russell Senate Office Building, Room 231
Washington, D.C. 20510

Dear Mr. Lombard:

Submitted herewith in response to your suggestion of June 26, 1974, is a statement by Combustion Engineering, Inc. related to its advanced transportation needs for use in the mid-July hearings on Advanced Aeronautical concepts by the Senate Aeronautical and Space Sciences Committee.

The statement is, of necessity, brief and is based on existing data. Work now in the planning stage is intended to provide a broader definition of advanced corporate transportation needs.

Included herein also per your suggestion is a brief personal biographical sketch.

Sincerely yours,

Stephen J. Keating Jr.

Stephen J. Keating, Jr.
Program Manager
Airborne Heavy Lift Transportation Systems

STATEMENT
to the
Senate Aeronautical Air Space Sciences Committee
on
Advanced Airborne Transportation Needs
by
Combustion Engineering, Incorporated

Mr. Chairman, I appreciate the opportunity to present the views of Combustion Engineering, Inc. on its future transportation needs primarily with respect to the transport of its Nuclear Steam Supply System components. Concern with future transportation requirements are not unique to Combustion Engineering in the electric power industry but may vary in degree from vendor to vendor. In all cases, the trends are similar. It should be noted here that delivery means using existing technology do exist for all units booked or proposed to date, however C-E recognizes that there can be strong economic incentive to utilize alternate means based on new technologies. C-E is not averse to seriously considering these means.

Nuclear Steam Supply Systems are characterized by very large, heavy components such as the reactor vessels which presently weigh over 400 tons and are over 40 feet long by 22 feet in diameter, and the steam generators which weight up to 800 tons, are up to 65 feet long and 21 feet in diameter. Equipment supplied by other vendors to complete the nuclear power plants such as the electric power generator rotor and stator, is of a similar size and weight.

Almost without exception in the past, such equipment has been transported from the point of manufacture to the point of installation by barge to plants sited near navigable water. However, in the very recent past there has been a significant trend away from plant sites near navigable water with the result that the large components must be transshipped from the barge at the nearest port and then transported over land by expensive, time-consuming methods to the remote sites.

The trend away from navigable water is due to several causes, amongst which are the rapidly increasing cost of suitable water-edge real estate, the proliferation of safety-related regulations such as population exclusion laws and the environmentalist pressure to minimize thermal pollution of bodies of water heretofore considered suitable as heat sinks for the thermal cycles involved.

The trend is made possible, not without significant added cost and penalties to operating effectiveness, by the shift to closed-cycle cooling systems characterized by cooling towers or cooling ponds.

Indications are that the trend to siting away from navigable water will continue. Based on the latest AEC projection (Case D) and assuming reasonable increases in average unit sizes, it is expected that over 700 nuclear units will be built in the period from 1981 to 2000, representing nearly 1,000,000 megawatts of installed electrical power and an investment by the utilities of about 500 billion dollars. An appreciable percentage of these plants will be located where the need to transport the heavy components overland will be imperative. Since anywhere from three to ten large components will have to be moved per plant and since by 1990 up to 20 units per year will be located remotely based on a conservative estimate, possibly 3 items per week may have to be brought to their destinations by overland transport modes.

Overland transport of these components by existing rail or highway modes can present problems, the foremost of which is associated with the size of the component. Rail and highway route clearances are sometimes not adequate to accommodate these large loads and so very expensive modifications to route-side and overhead structures and obstacles may have to be made or else detours involving in many cases intermodal transfers may have to be made.

Of alternate modes investigated to obtain relief from the restrictions of ground-based overland modes, the most likely to provide a good solution by relaxing dimensional limitations on the land may be an airborne mode based on the use of lighter-than-air technology in pure airships which obtain all their lift from aerostatic means or on hybrid airships which obtain lift from both aerostatic and aerodynamic means. To be most effective this mode will not require extensive and very expensive landing facilities in remote areas. Large payload weight would still present a formidable problem and in this respect much work would have to be done to develop suitable vehicles and to reduce component weight.

As an early step towards the use of airborne means to deliver the very heavy nuclear components, serious consideration should be given to other products such as tanks and ductwork which though very large, have characteristic weights several times smaller than the NSSS components. The benefits of shop fabrication of components provides a strong incentive for Combustion Engineering, Inc. to investigate alternate and more flexible shipping means. This would avoid the need to fabricate at the site large assemblies from parts whose size is dictated by the presently available transportation "windows".

In the furtherance of these goals, Combustion Engineering, Inc. has entered into a joint effort with Grumman Aerospace Corp. to investigate the feasibility of Airborne Heavy Lift Transportation Systems. The effort should provide some substantial answers to questions relating to the transport of electric power generating components by airborne means. C-E and GAC both recognize, however, that to justify the large development, certification and deployment cost of suitable vehicles by maximizing their utilization, other transport needs will have to be filled by the transport system.

The national and perhaps international survey for such needs and their evaluation and categorization is far beyond the scope of our present joint effort and our resources. Such a "mission definition" effort may belong under the aegis of a federal agency where contacts with competing systems and hardware vendors in areas such as the electric power industry to determine the overall industry needs will not be looked at askance by anti-trust elements and where the resources of many federal agencies such as NASA, DOT, the Department of Commerce, the Federal Power Commission and the Department of Agriculture can be efficiently marshalled.

Finally, the planning for such a system, once the needs are properly defined, should be conducted from a vantage point which insures the efficient maximization of its interface effectiveness with other, existing transport modes.

Stephen J. Keating, Jr.

Stephen J. Keating, Jr.
Nuclear Power Systems
Combustion Engineering, Inc.
Windsor, Connecticut 06095

July 8, 1974

July 26, 1974

Statement of

John C. Brizendine

President

DOUGLAS AIRCRAFT COMPANY

McDONNELL DOUGLAS CORPORATION

For the

Senate Committee on Aeronautical
and Space Sciences

NEW IDEAS FOR COMMERCIAL AIRCRAFT OF THE 1980s AND 1990s

It is a major challenge for the United States aircraft manufacturing industry to maintain its competitive position in world markets considering the energy problem, wide spread international competition, and the accelerating pace of research and development abroad. Meeting this challenge is made more difficult by the declining funds available in the United States to support aeronautical research and development. The introduction of commercial supersonic operations by the Concorde on major North Atlantic routes will shortly highlight the extent of the foreign competitive threat.

During the 1980s and 1990s strong and aggressive foreign competition is anticipated in several important areas of the commercial transport market: the second generation SST, the advanced medium range transport, and the very large second generation wide-body transport. To meet these challenges the funds available in the United States for aeronautical research and development must be wisely used.

Efforts must be concentrated in those research areas most likely to provide the technology base necessary for the development of aircraft that will be competitive in the world markets of the 1980s and 1990s. These airplanes need to be efficient, economical, appealing to the passenger and be environmentally acceptable to society.

The Douglas Aircraft Company appreciates the opportunity to share with the Committee our views on the roles and relationships of U.S. government and industry in aeronautical research and development in the face of the growing pressures from government supported international consortiums, and from the declining United States military aeronautical research and development that is applicable to commercial transports. It is a difficult task, at best, for government to be a leader in civil aeronautical development because of our free enterprise system and the many demands placed upon government by society.

The main thrusts of research and development for future aircraft can be broken into categories of long haul, short haul, and the advantages that can accrue due to the synergistic values of technology integration. Continued emphasis on technology research is required in propulsion, aerodynamics, avionics, structures and controls, with special attention to energy conservation.

The fuel savings made possible by the use of improved operating procedures for commercial aircraft will have been achieved well before 1980. Therefore, further energy savings can only be obtained through advances in technology applied to new aircraft. Efficient use of the nation's resources will dictate that the advanced technologies should be directed toward reducing fuel consumption per seat-mile as well as minimizing operating expenses.

In response to these goals and requirements the Douglas Aircraft Company is currently engaged in the preliminary design of a new advanced transport - the DC-X. To successfully design, develop and market this airplane, research in all the aeronautical technologies must be conducted. New advances that can be applied to both new and existing aircraft should be especially investigated.

Industry supported research and development in civil aeronautics between 1968 and 1972 has declined 43 percent. It is estimated that 1974 funding will be roughly equivalent to 1972. Research and development effort by major foreign competitors has, with full government support, significantly increased in this same time period.

In the early 1960s, United States military sales were roughly four times the level of free world commercial airplane sales; today they are about equal. Douglas forecasts indicate the civil sales markets will be double the military markets in the near future. It is, therefore, most important to our nation that we strive to maintain our world leadership role in civil aeronautics. The resulting benefits can be measured in terms of employment, balance of trade, prestige, national security, and an innovative technology base from which new products and increased productivity will accrue to the nation's industry.

In the area of long haul transportation, the public will express its interest in supersonic travel next year, 1975, when the Concorde initiates service. NASA sponsorship of research and development for both a near term advanced supersonic transport competitor and a longer term more sophisticated SST should be encouraged. United States industry may have lost too much ground

38-266 O - 74 - 16

to match an improved Concorde with a near term SST. Government leadership in research and development is a necessary ingredient to establish the technology base from which a competitive and economically viable advanced supersonic transport program can be launched.

In the area of short haul transportation, an important program is now underway at Douglas: the AMST (YC-15). It is progressing ahead of schedule and will fly in the fall of 1975. We are pleased that NASA is pursuing a flight test program in cooperation with us so our nation can realize the maximum benefits, both commercially and militarily from this exciting development activity.

A NASA funded system study of medium density air transportation being conducted by Douglas will assist in determining the technology areas and manufacturing techniques that should be emphasized if a commercially viable airplane that will provide efficient service to small cities is to be developed.

Specific areas of necessary research and development in the aeronautical technology areas are discussed in the proceeding sections.

PROPULSION

The present efforts to reduce specific fuel consumption, to increase bypass ratios, and to reduce engine noise must be continued. Recent studies, however, have identified additional areas of necessary propulsion technology refinement.

Past propulsion system weight reductions achieved by technology advancements have reduced the basic engine weight but not the weight of the nacelle that encloses the engine. In fact the weight of the complete nacelle has increased due to the need to include sound absorbing materials for reducing aircraft propulsion noise. This undesirable trend can be reversed by the use of composite materials in the nacelles.

An advanced engine concept which shows considerable promise is the variable pitch fan engine. Additional research and development is necessary to maximize cruise thrust to enable relatively high speed flight. Aircraft propulsion systems incorporating the variable pitch fan concept will have lower fuel consumption, be considerably quieter than even the quietest turbo fan engines and eliminate the need for separate thrust reversers which have been costly and troublesome items.

Recent advances have allowed the automation of engine throttle. This capability in conjunction with flight profile control can optimize energy management. The utilization of this capability to reduce fuel consumption warrants the allocation of research and development effort.

Theoretical studies dealing with the feasibility of using alternate energy sources for aircraft should be started. This work will provide the basis for valid technical decisions if it becomes necessary toward the end of the century for aircraft to use alternate energy sources such as liquid hydrogen, or liquid methane.

AERODYNAMICS

To support the design of aircraft that will be competitive in the world markets during the 1980-1990 time period, both analytical and experimental aerodynamic programs are needed.

Advanced airfoil research needs to be continued with emphasis on weight reduction rather than increased speed; thicker airfoils with improved maximum lift coefficients need to be studied.

The two largest components of drag, skin friction and induced drag, need to be re-examined to determine if drag reductions, not previously feasible, can now be achieved due to other advanced technologies. A good example is the use of the supercritical airfoils developed by NASA which can minimize the need for wing sweep and in turn makes laminar flow control easier.

Another case is the use of composite or advanced structural techniques. They may make feasible non-planar wing systems which reduce induced drag. Non-planar wing systems also have the potential for reducing wing tip vortices. If substantial reductions in the strength of these vortices can be achieved the spacing of aircraft approaching airports can be substantially reduced, thus increasing airport capacity.

Airport capacity at the already congested major terminals can also be increased by the use of advanced technology quiet aircraft, such as the DC-10, which provide increased capacity with reduced number of flights.

The effects on airplane aerodynamics of other emerging technologies in such fields as noise reduction and use of advanced composite materials must be evaluated and programs initiated to combine the technologies so maximum advantage will be taken of all the advances.

Since the design of an aircraft involves many variables, the greatest contribution that can be made to industry is the providing of basic analytical and experimental aerodynamic data which systematically covers a range of design options.

AVIONICS

The development of advanced digital avionic systems and of multifunction displays such as cathode ray tubes will permit major advancements in flight

management. Routine control of the aircraft flight path as well as of the aircraft systems can be automatic from takeoff through landing roll out. This advanced capability will permit the flight crew to function more efficiently in their capacity as managers due to their reduced workloads but with a greater awareness of the actual status of the airplane and its subsystems. The overall result of these advances will be increased safety.

STRUCTURES

Advanced structural concepts can make major contributions to assure that airplanes built in the United States during the period 1980-1990 will be competitive in world markets, efficient users of energy and economically efficient. It is possible to reduce the complexity of aircraft structural systems. Today's aircraft consists of a myriad of individual parts, much riveting and a large number of machined components. Studies indicate that the number of structural components can be reduced by about 12 percent, with a resulting weight reduction of about 8 percent. The use of a new structural technology concept, "Isogrid Panels", developed in the space program can result in a radical reduction in the number of fuselage parts and an 11 percent reduction in fuselage weight.

Another interesting structural concept is the use of composite materials in portions of future airplanes other than the engine nacelles. This use of composite materials was discussed in relation to propulsion technology. This concept has been studied for several years with increasing encouragement. Although these materials are more expensive than conventional aluminum, they are much lighter and the reduced airplane weight reduces fuel consumption. Advanced design studies also indicate that operating costs can be reduced by as much as 15 percent through the use of advanced composite materials.

The use of both isogrid structures and advanced composite materials will, however, require considerable research and development effort to establish the confidence necessary for their application to commercial aircraft.

CONTROLS

Advanced control technology may yield significant improvements in aircraft performance, longer life, and reduced fuel consumption as a result of lower skin friction and trim drags and will improve passenger comfort. Full time reliance on automatic control systems will require reliability levels at least equal to present systems. Significant milestones in flight control technology were achieved this past year. The successful flight testing by NASA of two pure fly-by-wire systems lend hope for the future of this advanced concept. Much work, however, remains to be done.

CONCLUSION

Focusing the nation's aeronautical research and development efforts on these promising areas will provide a technology base from which aircraft can be developed that will be competitive in the world markets of the 1980s and 1990s. These airplanes will be efficient users of energy and will have even better economic characteristics than present aircraft as well as being environmentally acceptable.

Fairchild Industries Germantown, Maryland 20767 (301) 428-6000

Wernher von Braun
Vice President-Engineering and Development

July 19, 1974

Honorable Frank E. Moss
United States Senate
Chairman, Senate Committee on
Aeronautical & Space Sciences
Washington, D. C. 20510

Dear Mr. Chairman:

In response to your letter of June 18, 1974, I am enclosing a statement I thought would be of interest to the members of your Committee.

Thank you for offering me this opportunity to present my views on a subject we here at Fairchild feel very strongly about.

Sincerely,

Wernher von Braun

Wernher von Braun

WvB:bas
Enclosure

SUBJECT: Hearings on Advanced Aeronautical Concept

STATEMENT

by

FAIRCHILD INDUSTRIES

Commercial air transportation in the United States faces two severe limitations which could result in our loss of world leadership in this field. The first limitation is concerned with performance. The cancellation of the Supersonic Transport program has constrained our future transport designs to operate in the transonic speed regime (0.9 Mach). The second limitation is the long term depletion of fossil fuels since present propulsion systems are totally dependent on petroleum based fuels. I believe both of these problems can be solved by leap frogging the current foreign SST program with the development of Hypersonic Transport utilizing liquid hydrogen fuel.

During the past ten years, studies were conducted on the technical/economic feasibility, and environmental impact of hypersonic transports. These studies were conducted by Fairchild and others for NASA and DOD, and showed that the following hypersonic transport aircraft were technically and economically feasible:

1. A 200 passenger transport having a range of 5000 nautical miles cruising at an altitude of 110,000 feet at Mach 6.0. Advanced turbofan-ramjet engines utilizing a liquid hydrogen fuel were defined as the most efficient propulsion system to accelerate to and cruise at Mach 6.0.

2. The feasibility of a more efficient 320 passenger transport configuration having a range of 10,000 nautical miles cruising at an altitude of 140,000 feet was also investigated. The propulsion system for this configuration consisted of turbo-ramjet accelerator engines for take-off to Mach 3.5 and an annular convertible scramjet burner to accelerate from Mach 3.5 to Mach 12 cruise. Again, liquid hydrogen fuel is required for this propulsion system.

The advantages beyond that of higher speed performance are significant. The sonic boom problem is *non-existent* since cruise at 110,000 feet altitude results in acceptable pressure increases at ground level. Further, the use of liquid hydrogen fuel eliminates the atmospheric pollution caused by the emission of unburned hydrocarbon and carbon monoxide since the combustion of hydrogen results in water vapor.

The development of a production Hypersonic Transport is possible by the late 1990's without overtaxing our resources, and should become a national objective like the Apollo and Space Shuttle programs. Research is required in aerodynamics, advanced structural materials, propulsion, guidance systems and ground support concepts. The Hypersonic Transport program deserves your support and consideration as a means of perpetuating U. S. leadership in air transportation.

#########

General Dynamics Corporation
Pierre Laclede Center
St. Louis, Missouri 63105

David S. Lewis
Chairman and Chief Executive Officer

314-862-2440

August 5, 1974

The Honorable Frank E. Moss, Chairman
Committee on Aeronautical & Space Sciences
United States Senate
Washington, D. C. 20510

Dear Senator Moss:

This is in response to your letter of June 18, 1974, in which you afford us the opportunity to present a statement on Advanced Aeronautical Concepts. It is my understanding that your hearings will cover new aircraft design, new engines and fuels, lighter-than-air vehicles and general aviation and safety.

While all of these areas are of interest to the General Dynamics Corporation, our expertise, within the concept of your hearings, is primarily in new aircraft design. As you know, General Dynamics has pioneered in the field of advanced aircraft design, having produced the first supersonic interceptor (the F-102), the first supersonic bomber (the B-58) and the highly regarded F-111 which, with its variable-geometry wings and its automatic terrain following radar/flight control, has proven to have a unique capability as a deep penetration vehicle.

More recently, General Dynamics was one of the two aircraft companies chosen to produce a new and advanced lightweight fighter. We have produced two of these aircraft as prototypes and both of them are now flying at Edwards Air Force Base, California, for testing purposes. I am attaching a copy of a paper dealing with the genesis of the lightweight fighter program along with a description of the YF-16, the General Dynamics version of this aircraft. We have detailed many of the innovative and unique characteristics of this new and inexpensive fighter to illustrate some of what we feel should be considered in the coming years.

Particularly, we would urge the committee to give strong consideration to advanced composite material research and applications as a means of coping, not just with the energy crisis to which you referred in your news statement of June 14, but also with the critical materials shortages

that are already becoming apparent throughout the aerospace industry. General Dynamics' experience with these materials in the YF-16 and F-111 programs indicates they may hold great promise as viable light-weight substitutes for existing materials.

Again, I appreciate your thoughtfulness in offering us the opportunity of sharing our experiences with your committee.

Sincerely,

David S. Lewis
Chairman of the Board

THE GENERAL DYNAMICS YF-16 FIGHTER

Background

During the original "F-X" studies that eventually led to the development of the F-15, General Dynamics investigated the concept of a lightweight, very highly maneuverable, day fighter. Although this concept did not meet all of the requirements for the "F-X," and was not proposed as such by General Dynamics, it did arouse support within the U. S. Air Force that led to funded studies in 1970. This concept was continuously studied and refined, and eventually served as the basis for the General Dynamics response to the Lightweight Fighter Prototype request for proposals.

Configuration Rationale

To obtain the best fighter performance, total integration of the aircraft design is required. Although thrust-to-weight ratio, wing loading, aspect ratio, etc., are all important parameters in defining a high performance fighter, they are only useful if the pilot can use that performance to maneuver without fear of losing control.

To realize this objective, a large number of configuration alternatives were analyzed and tested in wind tunnels before the final selection. The configuration selected is a design utilizing a number of new technological advances that provide outstanding fighter performance at low cost.

Engine Selection

The engine cycle was a significant factor in defining the weight on the YF-16.

During the conceptual phase, two engines received primary consideration: a single Pratt & Whitney F-100 with a bypass ratio of 0.72, and two General Electric YJ-101s with bypass ratios of 0.2. Analysis showed that to accomplish the design mission with the YJ-101 engines would require an aircraft weighing 4,500 pounds more than one with an F-100 engine.

An additional factor favoring the selection of the F-100 engine was its development status and planned usage. Flight experience has proven to be the single most important factor regarding engine reliability, safety and durability. By the time the first production F-16s would be flying, the F-100 will have over 75,000 hours in the F-15 and would benefit from F-15 experience and improvements.

Integrated Advanced Technology

Throughout the history of aviation, advances in technology have primarily been used to design aircraft to go faster, higher, farther and with greater payloads. In the YF-16 design, however, a new technology has been adapted to reduce cost without degrading basic performance, thereby producing significantly smaller, lighter and simpler aircraft with far greater agility and combat capability than present designs.

The YF-16 incorporates a number of advanced technologies combined in no other aircraft. These are all designed to produce the best fighter pilot/ fighter aircraft combination possible.

Fly-by-Wire

After prioneering the "adaptive control system" in the F-111, this fully electronic control system represents the next logical generation for providing ideal flight handling characteristics throughout the flight envelope. Built-in safeguards permit the pilot to fly up to the absolute limits of the aircraft's capability without concern. At the same time, it is more reliable, survivable and maintainable at a lower cost.

Relaxed Static Stability

Because of the advanced adaptive characteristics of the fly-by-wire control system, the designer has been able to make use of previously unusable advantages of relaxed static stability to reduce drag and weight and to improve maneuvering performance while maintaining ideal handling characteristics.

Blended Body

This results in improved lift-to-drag ratios at higher angles of attack while at the same time increasing usable internal volume and decreasing weight.

Forebody Strakes

These result in greatly improved directional stability at high angles of attack. In addition, when integrated with the blended body, they significantly increase lift.

Automatic Leading Edge Flap

The leading edge flaps automatically move to the optimum deflection during flight, greatly improving the buffet-free maneuver capability of the aircraft as well as improved lift-to-drag ratios at high angles of attack.

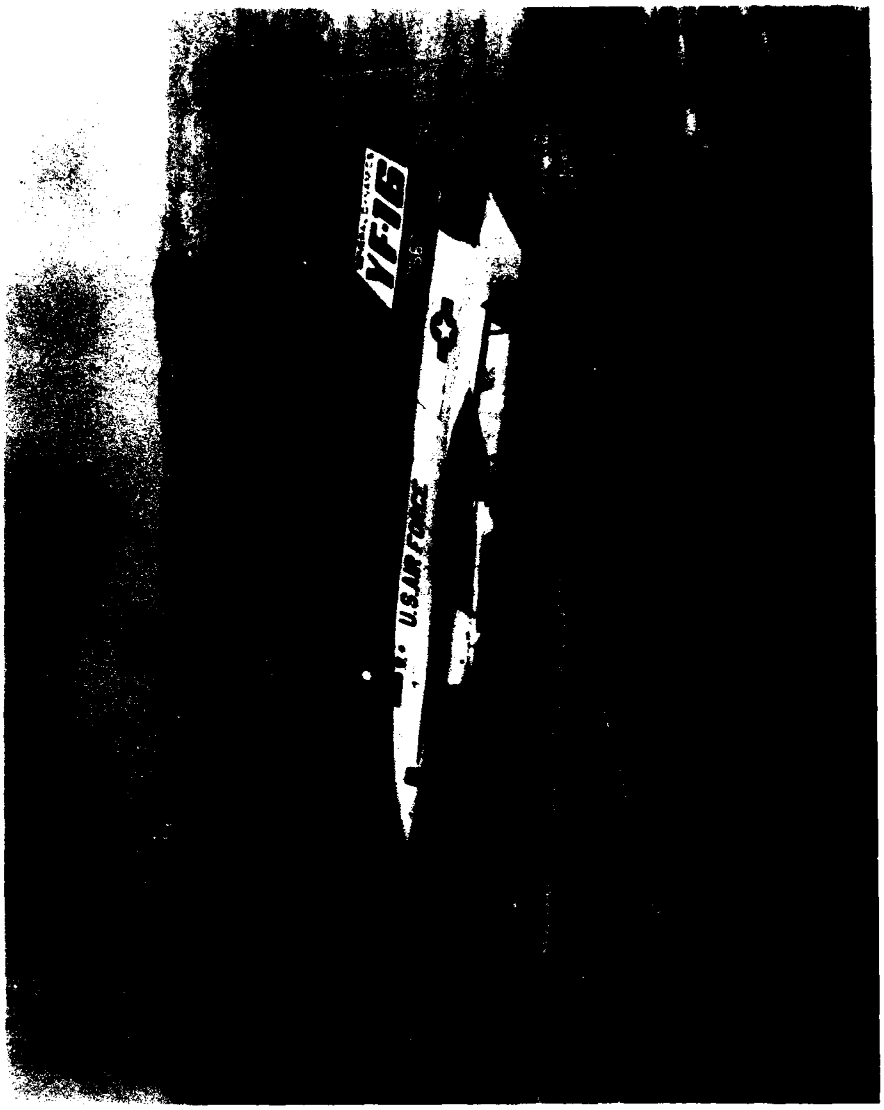
High "g" Cockpit

The 30-degree seat back angle coupled with the raised heel position results in a 1 to 2 "g" increase in pilot tolerance level and overall comfort. The minimum displacement, force sensing, side stick allows more precise pilot control, particularly under high "g" conditions. The full bubble canopy design provides the pilot with exceptional visibility.

Bottom Located, Fixed Geometry Inlet

Careful integration of the inlet geometry and location has resulted in a highly efficient design capable of 2.0 Mn without complex and costly moving ramps or bypass doors. The straightening effect on the air flow caused by the forward fuselage causes an increase in inlet efficiency at higher angles of attack.

As of July 31, 1974, the No. 1 and No. 2 prototypes of the YF-16 had completed 141 flights and had confirmed the results of these advanced technologies in providing a lighter and lower cost fighter compared with an aircraft of the same basic performance without them.


YF-16
U.S. AIR FORCE

STATEMENT OF J. N. KREBS
GENERAL ELECTRIC COMPANY
AIRCRAFT ENGINE GROUP

To the Senate Committee on Aeronautical & Space Sciences

General Electric has studied the presentations made by NASA, USAF, USN, DOT and the AIAA at the July 16 and 18 hearings of the Senate Committee on Aeronautical and Space Sciences and appreciates this opportunity to submit a brief statement about new technology for aircraft engines of the future.

Figure 1 is a summary listing of the advanced technology which we believe has the highest payoff for products of the 1980's. It is in fairly good agreement with much of the Government testimony presented, but there are some additional items listed and some items, mostly related to products of the 1990's and beyond, were eliminated. Figure 1 also shows the applicability of this technology and the funding status of R&D hardware programs - including NASA, USAF, USN, DOT, and GE programs. Where items are designated as having "reasonably adequate hardware programs" we are not suggesting that additional funding is not highly desirable - but rather that the next priority for any new funds are the items listed as not having adequate hardware programs.

Figure 2 is a summary and brief description of General Electric's recommendations for four new NASA experimental programs for products of the 1980's which need to be started soon. The concepts have been generated and hardware R&D is now essential for further progress. The first program is a variable cycle engine concept demonstrator, the next two are CTOL transport demonstrator programs, and the fourth is a subsonic VTOL demonstrator.

AIRCRAFT ENGINE TECHNOLOGY SUMMARY

	Highest Payoff Technology	Applicability: Military Engines Subsonic	Applicability: Military Engines Supersonic	Applicability: Civil Engines Subsonic	Applicability: Civil Engines SST	Reasonably Adequate Hardware Program Funded
Multipurpose Technology	• 400-600°F increase in combustor & turbine temperatures	✓	✓	✓	✓	Yes
	• Adv. high temperature superalloys for turbines	✓	✓	✓	✓	Yes
	• Composite material components	✓	✓	✓	✓	Yes
	• Lower Cost Manufacturing Processes	✓	✓	✓	✓	Yes
	• Higher efficiency, energy conserving components	✓	✓	✓	✓	No
	• Low emissions combustors	✓	✓	✓	✓	Yes
Special Purpose Technology	• CTOL subsonic systems					
	- Lower noise, energy conserving, composite nacelle (wide body transports, tankers, freighters)	✓		✓		No
	- Direct drive, variable pitch fan (ASW, patrol/surveillance, feederliner)	✓		✓		No
	• STOL subsonic systems (QCSEE)					
	- Geared, quiet, reversing, variable pitch fan			✓		Yes
	- Low noise composite nacelle	✓		✓		Yes
	• VTOL Lift Systems	✓	✓	✓		No
	• Variable Cycle Concepts		✓		✓	No
	• SST Exhaust Nozzle/Noise Suppressor				✓	No

Figure 1

Highest Priority Recommended New NASA Programs, Needed Soon	Applicability			
	Military Engines		Civil Engines	
	Subsonic	Supersonic	Subsonic	Supersonic
• Variable Cycle Engine - Concept Demonstrator New General Electric concepts provide bypass ratio control for improved installed performance of mixed mission (sub/supersonic) military & SST aircraft. GE proposes to demonstrate these concepts on a J101 engine modified to be typical of the cycle and arrangement of adv. fighter & SST engines. An advanced nozzle/suppressor would be tested on the SST VCE configuration.		✓		✓
• Energy-Conserving CTOL Transport Components & Demonstrator New technology is now emerging which will permit an 8 - 10% reduction in engine sfc and a 15 - 20% improvement in thrust/wt. - which combine to give 15 - 20% reduction in transport fuel usage. A high efficiency component program should be initiated - followed by an engine demonstrator program similar to the QCSEE STOL program.	✓		✓	
• Quiet, Energy-Conserving CTOL Nacelle Important reductions in the noise and fuel consumption of current wide body jets can be made with new concept of long duct nacelle with adv. acoustic treatment and composite construction. A full scale nacelle should be built and tested on the ground and in flight.	✓		✓	
• VTOL Lift Fan Demonstrator General Electric has proposed a program to design, build, and test an advanced VTOL turbotip lift-cruise fan system. This system is designed for use in a VTOL .8 mach Navy multimission aircraft and is also of the type which has been identified as a strong contender for future commercial VTOL transports.	✓		✓	

Figure 2

GOODYEAR AEROSPACE

CORPORATION

AKRON, OHIO 44315

15 July 1974

The Honorable Frank E. Moss, Chairman
Committee on Aeronautical & Space Sciences
U.S. SENATE
Washington, D.C. 20510

Dear Senator Moss:

Thank you for the opportunity to submit a statement to your Committee, which is holding hearings on Advanced Aeronautical Concepts during the month of July.

As the country's major manufacturer of airships for almost 50 years, Goodyear is in a unique position to provide information needed in formulating plans involving LTA vehicles. Besides the background as an airship supplier, Goodyear operates a fleet of airships for advertising, which also have been used in many public service activities. Your hearings are particularly important at this time. In recent months, considerable interest has been shown in the use of LTA vehicles for applications and operations not currently possible with other types of vehicles. The U.S. Navy and other services have manifested renewed interest in the unique capabilities of airships.

Goodyear has received inquiries about the use of airships in several innovative applications such as transportation of farm produce and over-sized payloads that cannot be conveyed on present highways and rail systems. Similar applications brought to our attention involve operations in areas where no other transport systems can operate, such as in the remote areas of Alaska and in emerging nations where it is not economically practical to develop and maintain highways or conventional aircraft transport facilities.

We believe that many of the applications being considered for LTA vehicles are practical, but unfortunately most of the applications taken alone do not justify the investment necessary to develop the required vehicle. It is of interest, however, and important to note that the type of vehicle desired for all applications is basically the same. Because of this basic similarity, Goodyear believes that the country's military and civil interests would be best served by Government support of a program for manufacture and operation of a vehicle that could be used to conduct mission evaluations for a broad spectrum of applications. Also, such a flying test bed vehicle could be used to evaluate the application of Space Age technologies to LTA system design. It could be implemented at a relatively low cost and would have the advantage of providing real performance information at an early date.

We are recommending to your committee the implementation of such a program using the design of the U.S. Navy ZPG-3W airship, which was the largest non-rigid airship ever manufactured.

This airship could operate either as a fully buoyant VTOL vehicle or in a hybrid or semibuoyant mode as a STOL vehicle using aerodynamic lift for increased payload capability. In the hybrid mode, the ZPG-3W payload capacity would be approximately 25 tons with an endurance capability of over 80 hours. Top speed of the original ZPG-3W was 75 knots.

This baseline design would be updated to incorporate new materials, avionics, structures, and propulsion technology to achieve a significant improvement in performance for today's missions. For example, it could cruise at 100 knots.

Also, the recommended vehicle would serve as a highly desirable platform to investigate and evaluate sensor payloads for military or civil missions. A typical civil mission would be use as a monitoring system for environmental, agricultural, and energy problems.

This approach offers a solution to the problem of avoiding the cost of implementing a new design by using an existing design as a program baseline for new developments.

In summary, we are confident that the field of LTA is an untapped resource now within our nation, particularly when we view the additional performance that can be achieved with a modern airship design. We would like to thank you again for the opportunity to respond to your request for a statement, and we look forward to an increased emphasis on the investigation of this type of air transport system.

Very truly yours,

GOODYEAR AEROSPACE CORPORATION

Morris Jobe

Morris B. Jobe
President

jk

ATTACHMENT TO GOODYEAR AEROSPACE LETTER, 15 July 1974

In recent months, Goodyear Aerospace Corporation has received nearly a hundred inquiries from both public and private business sectors related to potential modern airship applications. Sources of interest have included NASA, military, U.S. companies, local governments, and foreign governments.

This renewed interest can be attributed to four major factors:

1. A growing awareness of the ecological and energy problems associated with curr‿nt transportation systems.
2. The realisation that the operational characteristics and capabilities of airships are either not available or available only to a limited extent in other transportation systems.
3. The conviction that the quantum advancements in aerospace and aviation systems technology can place modern airships on the same level of safety, economy, and performance capability as alternate transportation systems.
4. The identification of many conventional and unique missions that modern airship vehicles could potentially perform cost effectively.

In contrast to these factors, certain limitations and purported deficiencies are often defined as also characteristic of airships. These broadly can be grouped as technical limitations, economic uncertainties, and institutional uncertainties.

Each of the four sources of interest, the technical limitations, and economic and institutional uncertainties are briefly discussed as well as one possible approach to eliminating the major stumbling blocks retarding the revival of modern airship vehicles.

ECOLOGICAL AND ENERGY FACTORS

The recent oil embargo and the resulting concern over the energy crisis has

resulted in an increased awareness of the dependency of our existing forms of transportation on the ever decreasing supply of petroleum. Commercial aircraft, one of the most severely affected transportation modes during the embargo, join private automobiles at the head of every list in terms of fuel energy consumed per passenger mile or per cargo ton mile. In contrast, modern-airship vehicles, because no fuel is expended in overcoming gravity, offer an extremely fuel efficient transportation mode.

A second area of increased public concern is the ecological and environmental aspects of air transportation. Demand projections for air transportation indicate that many major airports will be considerably overloaded in the near future.

Acceptable locations for the construction of major new airport facilities and STOL port facilities present an increasingly difficult environmental and land use problem. Also, the ground level noise environment in areas immediately adjacent to airport facilities, as well as the air pollution associated with commercial aircraft-ground operations, are significant considerations in the introduction and operation of future air transportation systems. In each of these eas, the operational characteristics of modern airships, such as vertical takeoff, low power requirements, operational flexibility, and safety, offer potential advantages as an alternate transportation mode for cargo and personnel.

The V/STOL capability, possibly augmented by vectorable propulsion for improved low-speed handling, eliminates the need for large runways characteristic of commercial aircraft operations. Essentially, airships require only a level clearing, not necessarily paved, with a radius slightly larger than the vehicle's length. A mast at the center of the clearing is used to tether the airship when it is on the ground and loading or discharging its cargo. In many applications, a landing would not even be necessary to discharge the cargo.

The lower power requirement results from the use of buoyant lift rather than aerodynamic lift. The decreased power requirements, in turn, results in reduced operational noise, decreased air pollution and potentially reduced costs, through reduced fuel consumption per unit productivity.

MODERN AIRSHIP CAPABILITIES

Although the unique capabilities of airship vehicles compared with existing aircraft are fairly well recognized, they will be briefly identified:

1. Safety, resulting from their relatively low takeoff and landing speeds and the fact that airships cruise at low altitudes, usually well below conventional aircraft traffic.
2. Carry bulky and heavy payloads, either internal in specially designed, containerized cargo bays, or suspended externally beneath the hull.
3. Virtually all-weather operational capability, with ground handling in severe weather further aided by vectorable thrust.
4. Exceptional endurance capability unparalleled by any air transportation vehicle. The 1.5 million cubic foot ZPG-3W built by Goodyear Aerospace and delivered to the U.S. Navy in 1958 had an endurance of 84 hours (3-1/2 days) at a cruise speed of 30 knots, on a fuel load of only 2500 gallons.
5. Operate where no airports or roads exist, unhampered by land-water interfaces. Hence, airships are more flexible than the airplane and could operate at a cruise speed (100 mph or greater) highly competitive with surface transportation without the surface transportation limitations (roads, tunnels, and underpasses, land-water interfaces, box car or rail car size constraints, etc.).
6. Hover for extended periods of time, particularly in the hybrid mode, combining static and buoyant lift with propulsive lift achieved through vectored thrust.
7. From an environmentalist's point of view, airships offer one of the most attractive transportation modes available. Both reduced air pollution and lower noise levels result from the lower power requirements.

8. Finally, from an energy conservation point of view, airships offer an extremely fuel-efficient transportation mode in terms of cargo ton miles or passenger seat miles per pound of fuel.

APPLICATION OF CURRENT TECHNOLOGY TO AIRSHIPS

Significant advances in structures, materials, and aerospace technology have occurred since the last detailed airship design effort was conducted. A few of the developments that could provide the highest payoff to airship technology include:

1. Extensive knowledge of weather patterns via Space Age weather forecasting and on-board weather radar.
2. More reliable propulsion systems with improved fuel consumption and power-to-weight ratios.
3. Higher strength-to-weight ratio materials: fabrics, metals, and composites.
4. Improved permeability plastics that will greatly improve helium retention.
5. Tremendously improved capability for the analysis and design of large rigid and semi-rigid airship structures resulting from the advent of modern high-speed computers and the developments of large-scale generalized structural dynamics analysis programs developed for Apollo and other NASA related programs.
6. Better insulation and high-temperature material capability to capitalize on the potential performance improvements resulting from super heating the lifting gas.

MODERN AIRSHIP MISSIONS

Perhaps the most significant factor contributing to the revived interest in modern airship vehicles is the identification of many rather unique missions for modern

airships. The missions most frequently discussed have arisen from a combination of the factors above: ecological and energy considerations, unique airship capabilities, and the promise of new technology. They may be loosely grouped into five general classes: commercial, public service, space related, AEC related, and military. Some of the most promising missions in each class are briefly described below.

COMMERCIAL MISSIONS

Commercial applications fall broadly into two groups: passenger missions and the more frequently discussed cargo missions.

Since the speed range of modern airships will probably be in the area of 100 nautical miles per hour, the most promising passenger missions are generally short-range applications similar to those performed by helicopters and proposed future V/STOL aircraft, including supplements to urban rapid transit systems.

Cargo mission applications have received the most interest of all modern airship missions. Oversized cargo transportation, such as nuclear reactors, cooling towers, factory assembled houses, massive pipelines, oil exploration equipment, and other large indivisible payloads are merely a few of the more promising applications. Modern airships could perform these missions irrespective of constraints applicable to either surface transportation or current air transportation modes.

Transportation of natural gas in a gaseous state is currently being investigated as an economically viable application. An airship transportation system of this type would possess flexible origin-destination alternatives.

Transportation of (perishable) bulk agricultural cargo is also gaining wide interest. The airship offers increased speed over surface transportation modes, flexible origin destination capability, and better ton/mile cost for low-density cargo compared with aircraft transports.

PUBLIC SERVICE MISSIONS

Several public service missions are currently under investigation at Goodyear or have been identified as potential airship applications. A Goodyear study recently

completed for the Tempe, Arizona Police Department clearly identified the capability of a police surveillance and crime prevention airship as a cost effective alternative to the noisy, fuel consuming, and fatiguing helicopter.

Another application under study at Goodyear, similar in some ways to the police surveillance mission, is an environmental surveillance and monitoring airship system capable of performing a variety of missions in the areas of air pollution, water pollution, noise pollution, and general ecological and environmental research.

A flying disaster relief hospital, capable of international service following natural disasters, is an additional application frequently identified. Modern airships could deliver hundreds of thousands of pounds of supplies several thousands of miles and distribute the cargo over a large area without depending on runways or airports. While it is unlikely that an airship would be developed uniquely for this purpose, if the initial development work were performed for some alternate mission, application to a flying disaster relief ship might be a realistic possibility.

SPACE RELATED MISSIONS

The Space Shuttle Transportation System will be one of the most-significant achievements of this century. This system will add a new dimension of cost effective flexibility to space travel. While the requirements for the initial shuttle flight-test program called for a capability beyond that of airship vehicles, i.e., the capability to air launch the massive, 150,000 pound orbiter vehicle, airships remain a viable, cost effective transportation system for ferry requirements and support of the operational shuttle system.

A preliminary shuttle transportation system has been defined by Goodyear Aerospace Corporation that can provide (1) orbiter portal-to-portal delivery, (2) solid-rocket booster recovery at sea, and (3) dry external tank and solid-rocket booster transportation, with minimum orbiter design impact. The airship transportation system could provide orbiter pickup and delivery throughout the existing airways system without elaborate, specialized equipment required to mount the orbiter "piggy-back" on a conventional aircraft.

AEC MISSIONS

Perhaps one of the highest benefit-to-cost ratio missions of future airship vehicles is a dedicated antonomous transportation system for nuclear fuel and nuclear waste material. Industry estimates predict 1000 nuclear power plants in operation by the year 2000, a 50-fold increase over the number operational in 1973. The increased risk of in-transit accident, accidental exposure, or subversive diversion of radioactive waste or fissionable material will probably exceed the 50 fold increase because of the increased traffic in the existing transportation infrastructure. The airship transportation system would operate independently of any existing transportation mode or terminal facility. Origin-destination points would consist solely of nuclear power generating plants, nuclear waste processing and disposal facilities, and nuclear fuel processing plants, each containing a secure area for payload transfer operations. The benefits of such a system result from a reduced risk of accident, reduced risk of radioactive exposure from transportation within the existing intermodal network, and a reduced risk of sabotage or subversive acquisition of radioactive or fissionable material.

An additional synergistic economic benefit may result from application of the same type of airship to the construction of the power plants themselves. Advances in cooling tower technology now make it possible, even desirable in many cases, to locate power plants away from major lakes and rivers, eliminating the utilization of barge transportation of major components. The cost of an airship cargo system capable of delivering large power plant components from the factory to the plant site could be significantly reduced by sharing the development costs with the dedicated AEC transport system. Furthermore, the actual construction costs might be reduced, leading to a net cost savings for plant construction, including the cost of the airship systems.

MILITARY MISSIONS

Important military applications result from two of the airships unique capabilities. The capability to deliver large quantities of men and supplies to remote areas over a long range without the need of extens[illegible] ground support provides a military

cargo or logistics capability beyond that of even the largest cargo aircraft. The extremely long-endurance capability of airship vehicles results in a platform uniquely suited to airborne surveillance applications: air, surface, and underwater.

Although the cargo carrier and troop transport applications are extremely viable missions, airship capabilities and characteristics are probably best suited to the over-water environment of naval missions. Some of the more promising Naval applications include surveillance of airborne and surface targets, airborne command control and communications, mine countermeasures, and ASW applications.

A surface surveillance platform having the massive size and volume of modern airship hulls is a significant advantage. Conventional or phased-array radar systems of unprecedented performance capability could maintain surveillance over an extremely large ocean area. Other sensor systems such as infrared and over-the-horizon radar could also be employed. The application of airships as an air surveillance platform is similar in many respects to the surface-surveillance mission, capitalizing on the capability to employ high-performance radar systems to detect and classify airborne vehicles. (The last squadron of Navy airships, the ZPG-3W built by Goodyear Aerospace, was designed to perform the air surveillance mission.) Modern airship air-surveillance missions would include not only aircraft but also cruise missile and submarine-launched ballistic missile applications. Incorporation of air-to-air missile capability on-board the airship would provide both a self-defense and an offensive attack capability against each type of airborne target.

Airships are extremely well suited to serve as a command, control, and communication center for area or fleet operations. Airships of reasonable size could house the most sophisticated computers, software, display, and communications equipment.

Airships could also be employed as excellent mine sweeping vehicles, in much the same way as the helicopters successfully employed in operation "End Sweep" in North Vietnam. By operating in air rather than water, the airborne mine sweeper can operate at reduced risk to both personnel and the mine sweeping vehicle. Airship endurance and self-sufficient operations capability offer significant advantages compared with the helicopter platform.

As an ASW system, airships could be used to tow extremely large aperture linear sonar arrays. Array performance would not be impaired by noise associated with a surface ship towing. Airship advantages would further include rapid deployment and redeployment flexibility as well as long endurance/on-station capability.

In an alternate ASW application, airships could be used to emplace and monitor large fields of sonar buoys. Target classification could be performed by the airship and ASW attack forces vectored against the threat submarine. On-board maintenance facilities would allow repair of damaged buoys recovered by the airship.

MODERN AIRSHIP PROBLEMS AND TECHNICAL LIMITATIONS

With the many promising missions identified for modern airships, it is worthwhile to address the technical limitations and purported deficiencies often cited as limiting airship applications.

In the military area, airships appear to be ideal platforms, particularly for Naval ASW missions. Since airships served as excellent ASW vehicles during WW I and WW II, the question arises why they were phased out of these missions.

The reasons most often cited include (1) insufficient speed, (2) increasingly sophisticated submarine technology relative to detection equipment capability, and (3) vulnerability.

As submarine performance and speed improved, the pressurized airships were unable to maintain the required 30- to 40-knot ground speed under severe sea-state conditions: 60-knot head winds. With today's propulsion and design technology, improved pressurized, semi-rigid or rigid airships could easily provide the performance capability required to overtake the fastest enemy submarine in virtually any weather condition.

The second factor that contributed to the airship's retirement from naval service was unrelated to airship capability. Submarine technological and operational improvements outstripped detection equipment capability, particularly the sonar detection range. Sophisticated advancements during the recent decade have resulted

in quantum improvements in ASW detection equipment. ASW airships could utilize the improved dunking sonar, towed array systems, large area sonobuoy fields, new magnetic anomaly detection gear and improved radar equipment, as well as supporting systems, including onboard data processing, readout analysis, localization, attack and data link systems developed for the S-3 aircraft and SH-3H and LAMPS helicopter ASW vehicles.

The final factor often cited in the demise of naval airships is their vulnerability. This topic seldom fails to arise when military applications of airships are discussed. In fact, recent developments in Soviet surface-to-air missile systems and antiaircraft artillery systems often leads to doubts about the survivability of even our least vulnerable attack aircraft. For airships, however, acceptable levels of survivability can be achieved by employing the airship in missions and tactical environments compatible with their unique design and operational characteristics.

Survivability could be improved by compartmentization of the lifting gas cells in large rigid and semi-rigid designs. Damage control and repair are feasible, since the structure and gas cells would be accessible to repair crews. More significantly, airships could be equipped with self-defense systems, early warning and fire control radar, anti-air and anti-missile missiles, and various electronic countermeasures to further enhance their survivability.

In the nonmilitary mission area, other problems often cited limiting airship applications include ground handling, ballast requirements during load transfer, control of buoyancy and trim, and airship response to severe gusts and turbulence. None of these areas constitute unsolvable technical problems or limitations utilizing existing approaches. However, airship performance and operational capability could certainly be improved by dedicated engineering design and development effort utilizing Apollo-era technology.

Ground handling of the latest and largest Navy airship, the Goodyear ZPG-3W, was considerably improved by the use of motorized "mechanical mules." Addition of vectorable thrust capability could also appreciably improve airship low-speed control characteristics during landing and ground handling. Vectored-thrust capability was employed by the Goodyear Akron and Macon rigid airships in the early

30's and could be appreciably improved utilizing 1974 technology. Small amounts of aerodynamic lift and vectored thrust could also be utilized for control of buoyancy and trim. Water recovery from fuel combustion products have been successfully applied for reclaiming ballast as fuel is consumed and warrants further investigation for modern propulsion systems. Initial heating of the lifting gas or intermediate, enroute ballast recovery are also promising avenues to buoyancy control.

Problems associated with airship response to severe turbulence can be minimized utilizing modern weather forecasting and navigation and avionics to avoid severe turbulence. However, modern rigid and semi-rigid airships would be designed to accept elastic deflections of the vehicle structure due to gust loadings. Modern computerized structural analysis and design capabilities would result in airship designs as air worthy as any modern aircraft.

Load transfer of massive cargo loads is an area that can benefit by actual flight experience and research and development efforts. Cargo/ballast load transfer approaches have been defined utilizing both water and solid ballast containers that simultaneously transfer the cargo to the ground and the ballast to the airship.

Other approaches that offer promising solutions to cargo transfer include small reversible bow and stern-mounted ducted propellers and internally suspended cargo transfer platforms free to rotate independently of the airship's response to ground winds. For many airship applications, cargo transfer actually presents no major problem not previously solved in airship operations. This area would require appreciable research and development only for the transfer of large (several hundred ton) indivisible loads characteristic of some modern airship missions.

Thus, none of the major technical problems or limitations often associated with airship applications to either a military or nonmilitary missions represent problems that have not been adequately solved in the past and could not be appreciably improved upon via modern technology. While modern applications might require airships of unprecedented size - 20 million, 40 million, perhaps even 100 million cubic feet - compared with the 6.5-million-cubic-foot Goodyear-built Akron and Macon, their development can be achieved by an orderly evolution from historical technology and experience.

The successful evolution will benefit significantly from the technology advancements of the last few decades and could be further enhanced by a research aircraft approach, not necessarily at full scale, aimed at investigations and improvement of airship operations particularly in the areas of ground handling, cargo transfer, and advanced buoyancy control and ballast recovery systems.

ECONOMIC UNCERTAINTY

The fundamental problem that has deterred the revival of airship utilization is economic uncertainty. Research and development cost estimates for large rigid airships have ranged from zero dollars by Airfloat Transport Limited of England to half a billion dollars. Cost estimates of pressurized airships similar to these last employed by the Navy can also be misinterpreted. Historical cost data generally reflect extensive engineering and design efforts to meet rigid performance specifications and achieve significant technological advancements in performance capability. Sophisticated military equipment, and airship design characteristics for its utilization, resulted in specialized design features and costs.

These uncertainties in the R&D costs and production costs for unknown production quantities directly affect the operating costs estimates via indirect operating cost charges to amortization, interest charges, insurance, fees, taxes, etc. Uncertainties in the ground facilities and personnel costs associated with performance of the many different mission applications further confuse operating cost estimates, which ultimately determine the economic viability of airship applications.

INSTITUTIONAL UNCERTAINTIES AND CONSTRAINTS

The third problem area that will affect the development of modern airship transportation systems for commercial applications may be defined or broadly grouped under the heading of institutional constraints. These include government regulations, state regulations, economic regulations, and so on.

The Federal Aviation Act of 1958 specifically requires the safety regulation of airspace, air navigation facilities, aircraft, aircraft parts, airmen, carriers, and certain airports. Historically, aviation safety policies have been issued and

38-266 O - 74 - 18

delineated through safety regulations issued under those requirements through the regulatory process. Furthermore, economic regulation cover transport of mail, persons, and property. Policy guidance in the Federal Aviation Act is broad, primarily looking toward the development of a safe and economically sound air network. Twenty-nine states have promulgated safety regulations applicable to intrastate operations. The range from simple registration and investigation of accidents to elaborate assurances of compliance with federal regulations.

Some of the major questions which arise in considering commercial applications include - How will airships be certified by the FAA? How will the airships be tested and how long will it take to develop commercial operation and safety standards? Who will operate modern airship vehicles? What International and National regulations and agreements will apply? Questions such as these must be considered in the successful introduction of modern airship transportation systems.

SUMMARY

The renewed interest in modern airship vehicles is based on several well founded facts.

1. Airships are an environmentally desirable and energy efficient alternative to existing transportation modes.
2. Airships have distinct advantages over existing transportation modes due to their unique operational capabilities.
3. Application of 1974 technology can significantly improve the capabilities of modern airships compared with vehicles of the past.
4. Because of the three facts above, many promising missions have been identified.

Factors that have prohibited the revival of modern airship missions are of three basic types: technical limitations or uncertainties, institutional constraints, and economic uncertainties.

In the technical area, the successful revival of modern airship vehicles can be achieved by an evolutionary program based on airship technology of the past, upgraded to reflect the technolcgy of today. With the possible exception of transfer of large indivisible cargos, technical problems do not exist that have not been solved in the past and could be significantly improved upon by the application, testing, and proving of equipment and operating techniques using 1974 technology.

The are of institutional constraints does not present any insurmountable problems but does deserve further investigation. Airship certification for commercial applications could be aided significantly by the availability of an airship for actual flight-test programs.

Economic uncertainty is the major problem retarding the development and successful introduction of modern airship transportation systems. Cost uncertainties arise from unknown production quantities and unknown costs. These uncertainties in turn actually result from unknown market size (<u>i.e.</u>, how many missions could

low cost and would have the advantage of providing real performance information at an early date.

We are recommending to your committee the implementation of such a program using the design of the U.S. Navy ZPG-3W airship, which was the largest non-rigid airship ever manufactured.

This airship could operate either as a fully buoyant VTOL vehicle or in a hybrid or semibuoyant mode as a STOL vehicle using aerodynamic lift for increased payload capability. In the hybrid mode, the ZPG-3W payload capacity would be approximately 25 tons with an endurance capability of over 80 hours. Top speed of the original ZPG-3W was 75 knots. This speed can now be increased to 100 knots with the use of more modern transportation.

This baseline design could be updated to incorporate new materials, structures, and propulsion technology to achieve a significant improvement in performance for today's missions. This flying test bed airship could be used as a scale test vehicle to experimentally investigate and develop airship operational capabilities as well as investigate advanced technology applications.

These investigations would include cargo transfer techniques, buoyancy control technology, ballast recovery systems, personnel minimized ground handling operations, incorporation of advanced avionics, as well as other improvements that could further enhance mission capability.

Also the recommended vehicle would serve as a highly desirable platform to investigate and evaluate sensor type payloads for military or civil missions. A typical civil mission would be used as a monitoring system for environmental, agricultural, and energy programs.

This approach offers a solution to the problem of avoiding the cost of implementing a new design by using an existing design as a program baseline for new developments.

In summary, we are confident that the field of LTA is an untapped resource now within our nation, particularly when we view the additional performance that can

airships cost effectively perform) and what characteristics (speed payload. range, etc.) the airship should possess to perform these missions and the costs required to develop such a vehicle.

Thus, a dilemma arises. Airship costs depend on quantity produced. Production quantity and airship characteristics depend on the numbers and types of missions airship can competitively perform. The number of missions that airships can perform is uncertain because actual flight testing and operational investigations have not been conducted due to lack of a research or test bed airship. A research or test bed airship is not available because of the uncertainty in what size airship should be developed and the cost to develop such an airship.

One approach to eliminating the development cost/applications dilemma and still providing a flight test and operational research airship is to construct the vehicle based on an existing, proven design, successfully built and flown in recent applications. This research airship or flying test bed could perform realistic, flight evaluations for a broad spectrum of mission applications and serve as a flying test bed for the evaluation of improved technological and operational approaches. This research airship approach could be implemented at relatively modest cost and the potential benefits of a viable, modern airship transpc :ation system are great.

CONCLUSIONS AND RECOMMENDATIONS

We believe that many of the applications being considered for LTA vehicles are practical, but unfortunately most of the applications taken alone do not justify the investment necessary to develop the required vehicle. It is of interest, however, and important to note that the type of vehicle desired for all applications is basically the same. Because of this basic similarity, Goodyear believes that the country's military and civil interests would be best served by Government support of a program for manufacture and operation of a vehicle that could be used to conduct mission evaluations for a broad spectrum of applications. Also, such a flying test bed vehicle could be used to evaluate the application of Space Age technologies to LTA system design. It could be implemented at a relatively

be achieved with a modern airship design. We would like to thank you again for the opportunity to respond to your request for a statement, and we look forward to an increased emphasis on the investigation of this type of air transport system.

GRUMMAN AEROSPACE CORPORATION
BETHPAGE, NEW YORK 11714

JOSEPH G. GAVIN, JR.
chairman of the board

31 July 1974

The Honorable Frank E. Moss
Chairman, Committee on
Aeronautical and Space Sciences
United States Senate
Washington, D. C. 20510

Dear Mr. Chairman:

In reply to your letter of June 18, I welcome the opportunity to comment to the Senate Committee on Aeronautical and Space Sciences. NASA aeronautica personnel are of extremely high technical excellence and are well motivated toward new and improved aerodynamic concepts. We remember well the aeronautical technical information made available to us through NASA and especially through the National Advisory Committee for Aeronautics prior to 1958 and recognize that these data played a most important role in the 45-year history of our company. It is further recognized that Space Age emphasis minimized NASA's aeronautical research work during the past 15 years. There is no shortage of new ideas for aircraft within NASA, but there is a need for increased funding for aeronautical research.

In this context and with the belief that NASA personnel are most capable in the selection and execution of the specific aeronautical research programs, I would like to offer the following thoughts to your Committee:

1. Retention of ecological goals is an important factor in future world markets. Low noise and low pollution are a must.

2. Fuel costs will play an increasingly important role in the selection and acquisition of systems in the future. We do not see a replacement for fossil fuel in aircraft in the next 15 years nor do we see an improvement in engine cycles which would yield any large reduction in specific fuel consumption. Application of lightweight structural technology and active load control promises relatively modest savings in fuel per passenger mile.

Additional savings can also be expected when the need for large quantities of reserve fuel can be markedly reduced through better weather forecasting and air traffic control.

Although we do not see any dramatic savings in fuel per passenger mile we believe that normal evolution of this parameter will be important to sales of future aircraft. We conclude that the only practical solution is to save as much fuel per passenger mile as possible and direct our national priorities to development of substitute fuels for energy uses that are ground-based and relatively insensitive to weight. Air transportation should have first priority on fossil fuels.

3. An excellent safety record is a prerequisite to future aircraft sales. Decreased approach and landing speeds through further development of high-lift and perhaps variable sweep technology is of definite interest. Military experience supports the lower speed-increased safety relationship and indicates that designing for lower landing speed will result in lower liftoff speed for additional safety benefit. Also, improved, more highly automated traffic control systems that minimize airspace congestion and reduce accident probabilities are needed. Greater emphasis should be placed on design of fail operational/fail safe aircraft propulsion and flight control subsystems.

In summary our message is: allow NASA personnel to select the detailed research programs with the overall goal of achieving a low noise, low pollutant, fuel efficient, and safe transportation system.

Thank you for the opportunity to present our thoughts to your Committee. I would appreciate receiving a copy of your Committee's findings. Please do not hesitate to call on me if I can be of further assistance.

Sincerely,

GRUMMAN AEROSPACE CORPORATION

J G Gavin Jr

Joseph G. Gavin, Jr.
Chairman of the Board

MR
Jim

LTV AEROSPACE CORPORATION
A SUBSIDIARY OF THE LTV CORPORATION

PRESIDENT

P.O. BOX 5907
DALLAS, TEXAS 75222

SEN. FRANK E. MOSS
RECEIVED
AUG 1 1974
WASHINGTON, D. C.

30 July 1974

Senator Fran E. Moss
Chairman
Committee on Aeronautical and
Space Sciences
New Senate Office Building
Washington, D.C. 20510

Dear Senator Moss:

Paul Thayer, President of The LTV Corporation, has advised me of your committee's hearings on Advanced Aeronautical Concepts and of your 18 June invitation to submit a statement for possible publication in the hearing record.

We welcome this opportunity to be heard, and LTV Aerospace's statement is enclosed for your consideration.

Sincerely,

Sol Love

Sol Love

Enclosure

S T A T E M E N T

on

ADVANCED AERONAUTICAL CONCEPTS

LTV Aerospace Corporation welcomes this opportunity to participate in these important hearings. While we currently are a producer of military rather than commercial or general aviation aircraft, we have been a major contributor to the advancement of aeronautics for more than half a century and currently are at work on some promising advanced concepts which could significantly increase the efficiency of commercial transport aircraft. We also would like to recommend the pursuit of several allied technologies which ultimately could result in substantial economic improvement in air transportation.

One of our advanced concepts utilizes a multi-bypass ratio propulsion system which can be integrated very well with the aerodynamic arrangement of an airplane to provide substantial benefits in performance and utilization.

Combined aerodynamic/propulsion approaches have been employed in the past, although with less effective synergetic relationships in mind. STOL and V/STOL airplanes, such as our XC-142 tri-service transport, were designed to utilize the propeller flow to improve the aerodynamics and control at low speed and hover. More recently, unique arrangements were introduced on the Advanced Medium STOL Transport project to induce an increase in wing lift through appropriate positioning of the turbofan exhausts.

The multi-bypass ratio propulsion system utilizes a cross flow fan, a device invented in the last century and perhaps best described as a linear air pump. The cross flow fan resembles a long, thin version of the familiar "squirrel cage" blower used in many heating and air conditioning systems, but it doesn't function in quite the same way. Rather than causing the air to flow in one end and out radially, the cross flow fan is configured to pump the air across the diameter. Pressure ratios, well exceeding 1.5 across the fan, are easily achievable and at efficiencies above 80 per cent.

This device, installed in segments along the trailing edge of a wing and driven by a turboshaft engine, takes in air from the bottom surface of the wing and blows it aft over the top of a properly configured wing flap. This fast-moving air could induce substantially increased wing lift at low speeds and high lift-to-drag ratios in cruise. At the same time, it functions efficiently as the primary thrust for the aircraft.

Thus, the system could approach the ultimate in terms of an efficiently-integrated aerodynamic/propulsion relationship for subsonic applications. It could result in a substantial reduction in power requirements, permitting use of smaller engines and dramatic reductions in fuel consumption over given performance ranges. It also has the potential for both subsonic and supersonic VTOL applications.

LTV Aerospace is exploiting the cross flow fan concept as one of its Independent Research and Development programs, and the Navy currently is sponsoring further development. The system

has very high potential across the subsonic commerc trans-port spectrum -- from the small inter-urban commuter to the large, transoceanic transport.

Recommended for further development and exploitation is an emerging array of advanced technologies which could improve the overall efficiency of commercial aircraft products. These concepts, when developed to their fullest potential, could lead to reduced weight, reduced cost and reduced maintenance while substantially increasing reliability. They include:

o <u>Advanced metallic structural concepts</u> which, when developed, will provide for the combination of new structural design concepts with the new developments in airframe fabrication.

Advanced alloying of existing materials currently under development will provide competitive strength properties while enjoying better fatigue and corrosion resistance characteristics. These characteristics will result in lower fabrication and quality control costs plus lower service maintenance costs. The advanced fabrication techniques will include low cost castings, laminated bonding of skins and parts and the reduction of previously required mechanical fasteners by combining bonding and riveting in various combinations for even additional cost reduction.

o <u>Composite structural materials</u> are now beginning to be recognized for use in the production of airframe components at costs competitive with conventionally fabricated metallic structures.

Weight savings of 20 to 30 per cent are already being achieved by using these composites. The materials lend themselves to fabrication by automatic, numerically controlled tape-laying machines, a procedure which permits production of large components without joints while substantially reducing labor costs. Further development and usage of composite materials will result in additional cost and weight reductions.

o <u>Electrical/electronic digital (fly-by-wire) control systems</u> will result in reduced control system weights, volumes and production and maintenance costs as compared to the electro-mechanical systems employed in today's aircraft designs. Most important, however, is the realization that the fly-by-wire concept is the necessary key to the exploitation of . . . . .

o <u>The control configured vehicle (CCV)</u> principles which will provide for lower aerodynamic drag, improved ride qualities and gust load alleviation, all of which will reduce the empty weight and fuel required.

The future of commercial air transportation, currently being impacted by the restrictions of the energy crisis, could very easily be affected by accelerated research and development programs in these and other advanced aeronautical concepts.

# # #

LOCKHEED AIRCRAFT CORPORATION
BURBANK, CALIFORNIA 91503

RONALD SMELT
VICE PRESIDENT
CHIEF SCIENTIST

July 25, 1974

Senator Frank E. Moss
United States Senate
Committee on Aeronautical and Space Sciences
Washington, D.C. 20510

Dear Senator Moss:

We appreciate the opportunity to respond to your request to Mr. Kotchian of June 18, to contribute material pertinent to your recent hearings on Advanced Aeronautical Concepts.

The attached brochure, entitled "Air Transport Technology Needs," focuses on many of the key aeronautics technology issues of the next decade and suggests some priorities on our future research and development efforts. It further highlights our concern that the aeronautical effort and funding within NASA represents a very small fraction of the total NASA program. In no way do we question the wisdom and desirability of a strong space program. Rather we suggest that, in the face of the strengthening off-shore threat to the U.S. commercial air transport industry and the low levels of new military aircraft development, NASA could profitably increase its aeronautical contribution with a relatively small effect upon its total budget.

It is also our hope that your Committee in its deliberations can spend some time in considering the mechanisms whereby new concepts make the transition from federal laboratories to the airplane inventory. NASA and DOD have usually stimulated new concepts to the point where feasibility and potential merit were clearly established. This is an essential first step in which the government laboratories have been, and continue to be, outstanding. However, two further steps remain in the transfer of new technology to new aircraft and we can foresee difficulties in both of these, particularly in the commercial field.

Immediately following the demonstration of feasibility of a new technology, it is necessary to perform a large number of detailed engineering tasks to ensure that the new concept is satisfactory in all respects. A current illustration is

the concept of graphite composites as structural material for aircraft. We have now demonstrated that we can make such material, with strength and stiffness superior to conventional metallic aircraft structures, at a competitive cost. It now remains to show that these materials will remain satisfactory for a typical aircraft service life; that they have no disqualifying corrosion problems; that they will survive lightning strikes; that field repair techniques can be developed; and a host of similar detailed engineering tasks which must precede their operational use. In the past we have grossly underestimated the magnitude of this intermediate task between feasibility demonstration and operational deployment. We would strongly urge that funding be made available for NASA and DOD to play a greater role in this phase.

The final step in transfer of any new technology to the operational phase requires that difficult decision on the part of the aircraft industry, the airline or the government to accept the risk of a new concept for its promised improvement. This risk is minimized with good engineering development but history shows that it is never completely absent. There is little doubt that the present climate in the aerospace industry is not conducive to the assumption of high risk. Both financial and economic factors militate against the acceptance of significant risk and the financial community already rates the airline and aircraft industries as speculative fields for capital investment. Unless steps are taken to change this position, and to provide returns for these industries commensurate with the risks taken, the U.S. aeronautical industry will find it difficult to continue its past record of high technology application which has led us to our current position of international dominance in the air transport field.

Sincerely,

Ronald Smelt

Ronald Smelt

Enclosure

AIR TRANSPORTATION TECHNOLOGY NEEDS

Submitted as supplementary data to the hearings on Advanced Aeronautical Concepts before the U.S. Senate Committee on Aeronautical and Space Sciences, July 16/18, 1974.

LOCKHEED-CALIFORNIA COMPANY • BURBANK, CALIFORNIA
A DIVISION OF LOCKHEED AIRCRAFT CORPORATION

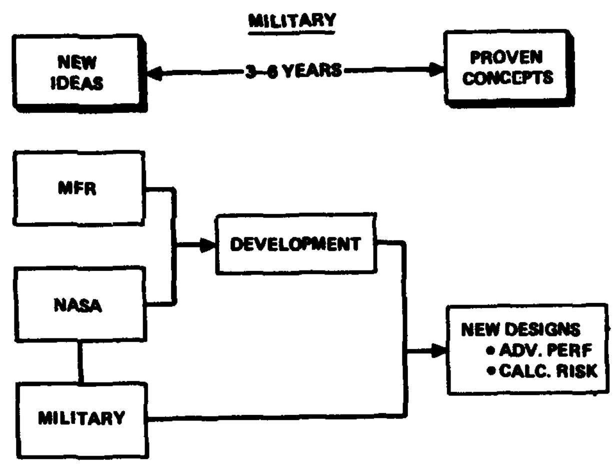
TRANSPORT AIRCRAFT EVOLUTION – MILITARY

New aeronautical ideas emanate from research performed by NASA, airframe and engine manufacturers, and the military. Ideas are explored, theories are developed, and experimental verifications are established in various development programs.

From these activities emerge new aeronautical approaches that require proof of concept including actual airplane operation. In the past these first steps involved the military working with manufacturers, with NASA as technical advisors. Emphasis was placed on new high performance military airplanes. In general these adopted advanced technologies which imposed a calculated risk on the level of confidence of success. Many new ideas were tried; many experimental aircraft were built and tested. From these emerged proven concepts that provided significant practical improvements in aircraft design and operations.

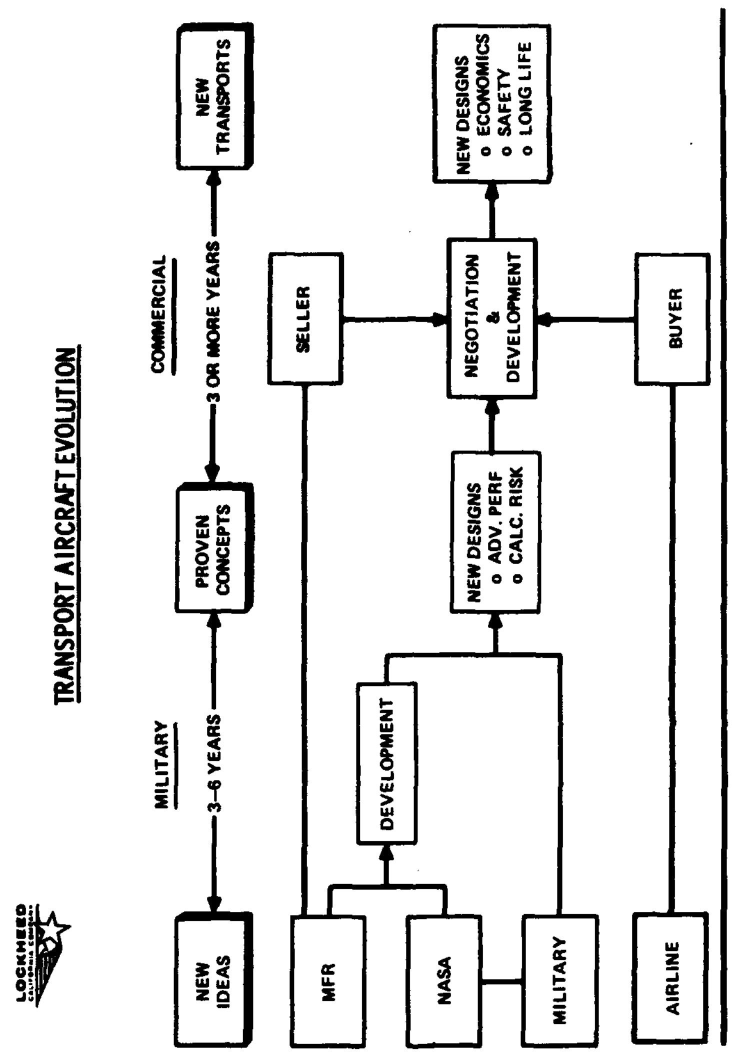
38-266 O - 74 - 19

TRANSPORT AIRCRAFT EVOLUTION



TRANSPORT AIRCRAFT EVOLUTION – COMMERCIAL

Much of the progress in commercial air transportation has resulted from the technology advances that have emerged from military programs. With new proven concepts, the airframe and engine manufacturer could confidently propose new advanced transport designs to the airlines, with assurance of improved economic potential, better safety, and long life design. The airline purchaser had confidence that these new advances were practical and his risk and commitment to buy was protected by previous demonstration.

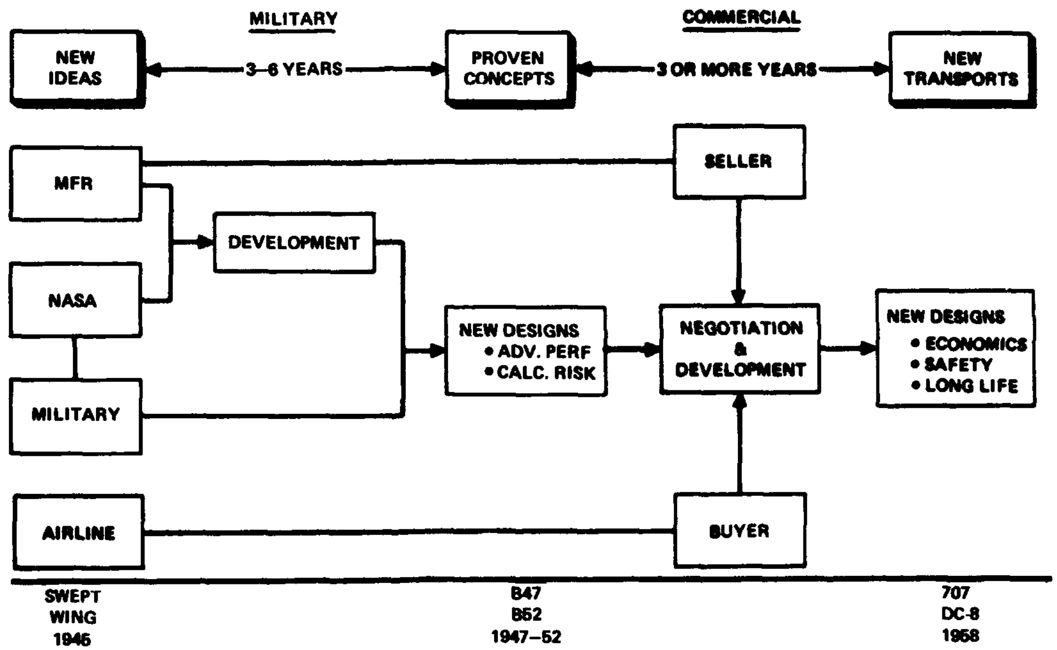

TRANSPORT AIRCRAFT EVOLUTION
LOCKHEED
MILITARY
COMMERCIAL
NEW IDEAS
3–6 YEARS
PROVEN CONCEPTS
3 OR MORE YEARS
NEW TRANSPORTS
MFR
NASA
MILITARY
DEVELOPMENT
NEW DESIGNS
o ADV. PERF
o CALC. RISK
SELLER
NEGOTIATION & DEVELOPMENT
BUYER
NEW DESIGNS
o ECONOMICS
o SAFETY
o LONG LIFE
AIRLINE

TRANSPORT AIRCRAFT EVOLUTION – EXAMPLE

An example of the evolution from new idea to practical commercial transport is the swept back wing. Conceived during World War II, this aerodynamic advancement was developed, beginning in 1945 in NASA wind tunnels. The first large aircraft to adopt the concept were the B47 and B52 bombers, at the end of the 40's. These airplanes paved the way towards resolving the low speed handling qualities and structural problems involving wing deflection and flutter, which are all aggravated by the swept wing. The first commercial transports to adopt this concept appeared in 1958, 13 years after the new idea first emerged, and 11 years since the first large swept wing airplane had flown.

LOCKHEED CALIFORNIA COMPANY

TRANSPORT AIRCRAFT EVOLUTION



REF. RADCAP REPORT

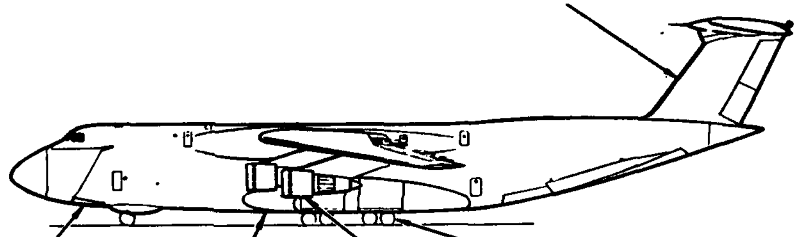
C5 SPIN OFF

The wide bodied transports of this decade have all been recipients of technology advances from military development, including the large Air Force Galaxy cargo transport (C5A). This design introduced many of the new problems that relate to doing things on a bigger scale – manufacturing, handling, testing, and controlling. New engines were developed and new control systems for large aircraft were made practical.

The C5A, built by Lockheed, involved many airframe and supplier compenies throughout the country. Thus experience and skills for large commercial transport development and manufacture were available as the 747, DC10, and L-1011 designs came upon the scene.

LOCKHEED

C5 SPIN OFF



PARTICIPATING STATES 40

MILITARY AIRCRAFT INVENTORY

The transport airplane evolution process just described is in process of change. The numbers of military aircraft being developed today are far less than were in the inventory when the Electra was introduced in 1958. For the next generation of new transport designs, only a few new large military aircraft will be operational and in a position to offer proven technology advances. One result of this trend will be a reversal of the traditional technology flow from military to commercial aircraft.

LOCKHEED
CALIFORNIA COMPANY

MILITARY AIRCRAFT INVENTORY

1958 ELECTRA	1968 TRISTAR	198X
		?
C-97		
C-121		
C-124		
C-130		
C-133		
C-135		
B-52	C-141	
B-58	XB-70	
YB-60	FB-111	
YP-6M	C-5	B-1
R-3Y	F-12	AMST

FUTURE TECHNOLOGY EMPHASIS

Not only *will there be fewer aircraft* types in the military inventory; there will also be diverse emphasis on technology application. The military, as always, will stress superior weapon systems capability, with need for better aerodynamics, structures, and propulsion. *The commercial sector*, while desirous of all the military payoffs in these same areas, will require that their new transports meet noise and emission standards, and properly reflect possible impact of the energy problem. The commercial sector will *continue to require* technology enhancement leading to improved economics, safety, and long life.

LOCKHEED
CALIFORNIA COMPANY

FUTURE TECHNOLOGY EMPHASIS

ITEM	MILITARY INTEREST	COMMERCIAL INTEREST
NOISE		✓
POLLUTION		✓
CONGESTION		✓
ENERGY		✓
SAFETY	✓	✓
MANEUVERABILITY	✓	
POWERED LIFT	✓	✓
COMPOSITES	✓	✓
ACTIVE CONTROLS	✓	✓
AVIONICS	✓	✓

FUTURE TRANSPORT DEVELOPMENT

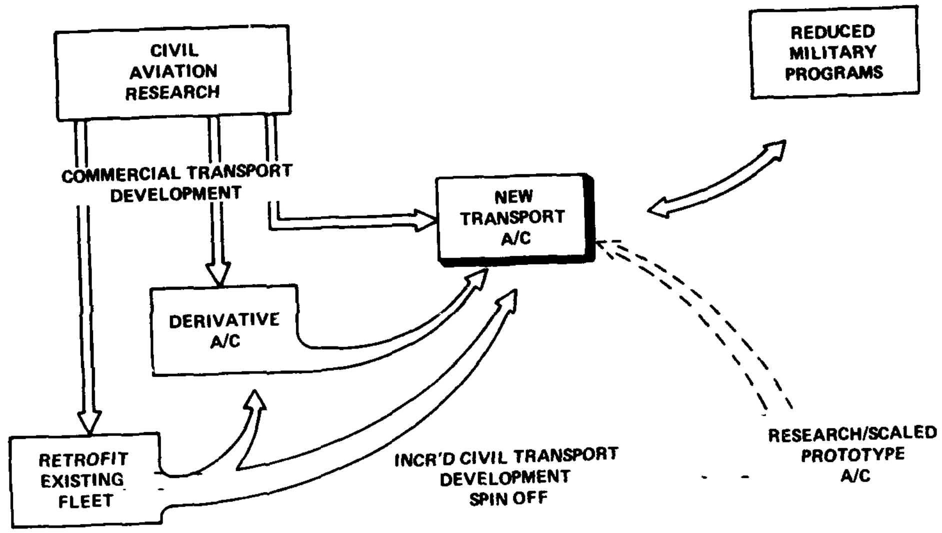
With fewer military aircraft under development, and technology emphasis not directly focused on ecology, future transport development will take on a more gradual evolution process. Greater attention must be given to civil aviation research and development programs by both the government and *airplane manufacturers*, and there will be greater reliance on use of existing transport aircraft to develop new concepts and product improvements on a retrofit basis. This will mean longer active service life for the new transports.

There will also be a *greater number of* derivative aircraft developed from the baseline design. These will go beyond *the stretched fuselage versions* that are common place today. Changes in power plant, wing, structural materials, *and high* lift aerodynamics may all appear on advanced versions of today's transports.

An all new transport design will be slower in coming, and will be the *recipient of spin off from the retrofit and* derivative transport programs. When appropriate, *benefits from on-going military programs* will also be employed. There will also be spin off from the new *commercial transport* to the military. This suggests that there would be mutual gain if the commercial and *military* users of future aircraft could search for commonality of purpose and design, and identify similar airplane concepts that can satisfy both specific needs.

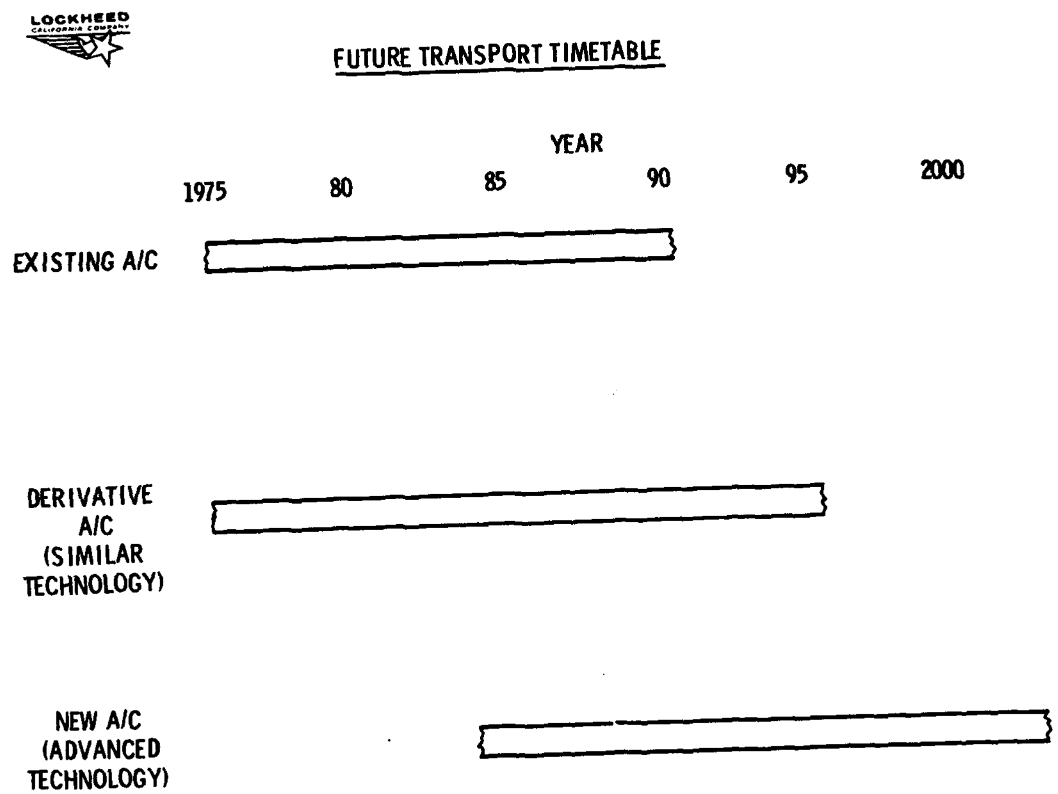
LOCKHEED

FUTURE TRANSPORT DEVELOPMENT



FUTURE TRANSPORT TIMETABLE

The newer wide bodied aircraft entering service now will have an active service life extending to the early 1990's. Derivative versions, which may appear within the next five years, will provide service to the mid 90's. New advanced technology transports will probably not enter service much earlier than 1985.


LOCKHEED
CALIFORNIA COMPANY
FUTURE TRANSPORT TIMETABLE
YEAR
1975
80
85
90
95
2000
EXISTING A/C
DERIVATIVE A/C (SIMILAR TECHNOLOGY)
NEW A/C (ADVANCED TECHNOLOGY)

NEW TRANSPORT CONSIDERATIONS – ISSUES

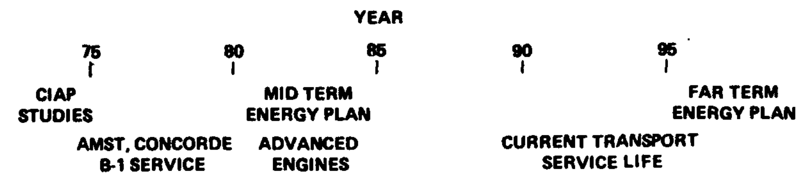
A number of issues will influence the service entry date for the next generation new transport. Both ecological and energy conservation study programs are proceeding at present; their findings will impact in future airplane design. The Climatic Impact Assessment *Program* (CIAP) is involved *with upper atmospheric emissions and their impact* on the ecology. Study of the possible fuel oil depletion problem, and the *related* production of fuel from coal and shale, and the introduction of alternate forms of energy will all be given high priority attention in the next decade. Findings from these efforts will strongly influence future airplane design.

Use of synthetic forms of hydrocarbon fuel may appear to be possible in the mid 80's. Or perhaps alternate fuels (LH_2) at the end of the century may be looked upon as the most practical world-wide solution.

In the next decade, service operation of the Concorde and TU144 will shed some light on public enthusiasm for higher speed transportation at premium fares, and the importance of sonic boom generation on a scheduled basis. The B-1 bomber will also add supersonic flight experience and demonstration of new advances in technology. The AMST program will demonstrate powered lift practicality.

LOCKHEED CALIFORNIA COMPANY

NEW TRANSPORT CONSIDERATIONS

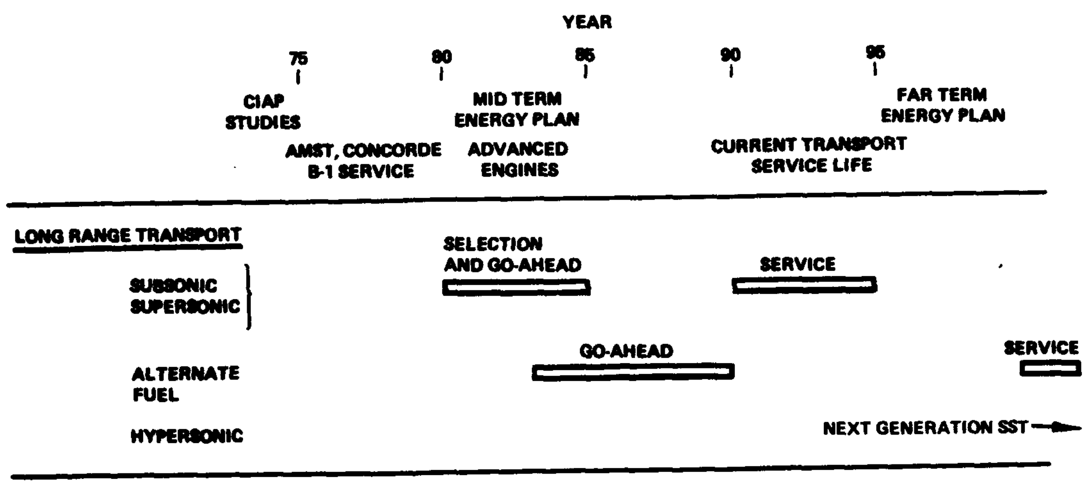


NEW TRANSPORT CONSIDERATIONS – LONG RANGE TRANSPORTS

The next generation long range transport may not see service until the late 80's. In the mid 80's a choice will be made as to whether this new airplane should be subsonic (in response to severe energy conservation needs) or supersonic. Or the option might be to hold off and prepare for an end of the century alternate fuel airplane design (probably a liquid hydrogen powered supersonic transport). The hypersonic transport does not appear to be a near term option, but rather a second or third generation SST.

LOCKHEED CALIFORNIA COMPANY

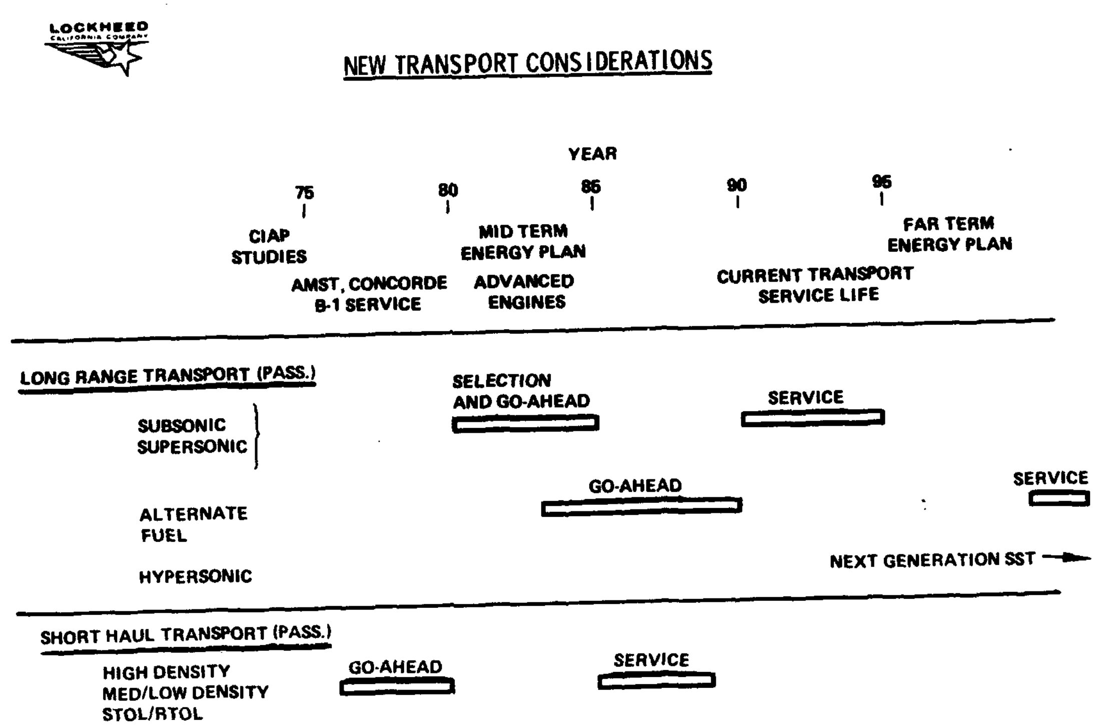
NEW TRANSPORT CONSIDERATIONS



NEW TRANSPORT CONSIDERATIONS – SHORT HAUL TRANSPORTS

Appearance of a short haul transport in the last half of the 80's appears feasible. This design could be a derivative of the existing fleet (with newer engines or new wing), perhaps with powered lift application to provide a measure of STOL or reduced takeoff and landing capability. It may be a totally new design incorporating advanced technology in all fields.

Two types of airplanes will probably be needed to serve the total short haul market place. A high density version is likely in many areas where highly populated cities can support high capacity traffic. A smaller low to medium density design is anticipated to meet the needs for serving lower density population centers by the local service carriers.

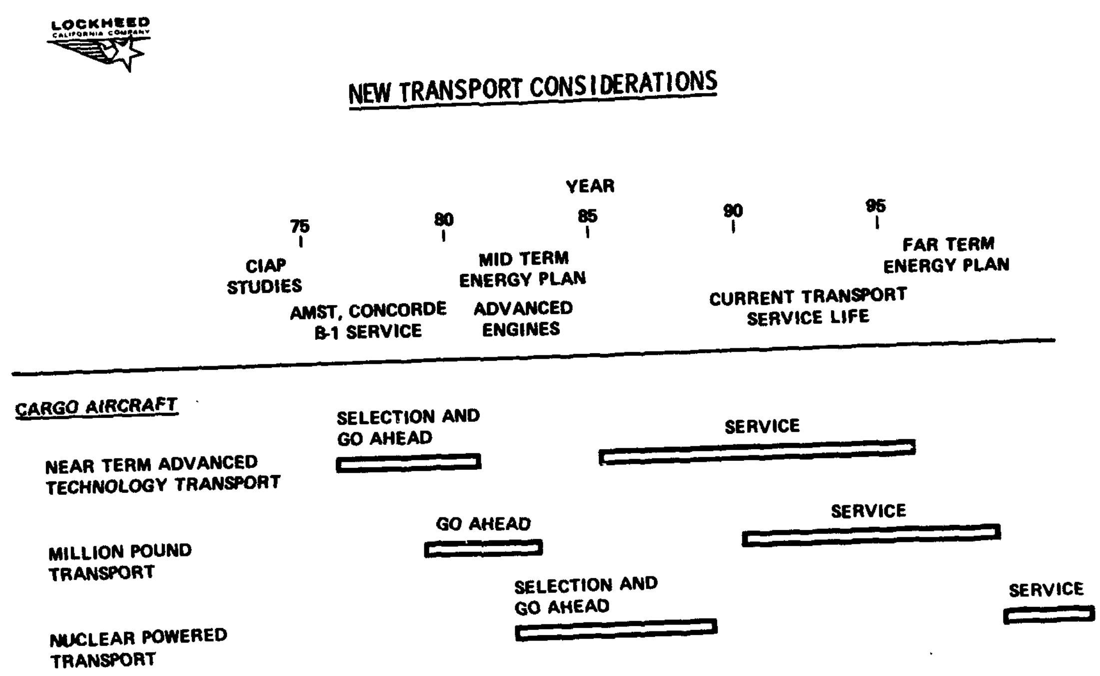

LOCKHEED CALIFORNIA COMPANY
NEW TRANSPORT CONSIDERATIONS
YEAR
75
80
85
90
95
CIAP STUDIES
AMST, CONCORDE B-1 SERVICE
MID TERM ENERGY PLAN
ADVANCED ENGINES
CURRENT TRANSPORT SERVICE LIFE
FAR TERM ENERGY PLAN
LONG RANGE TRANSPORT (PASS.)
SUBSONIC
SUPERSONIC
SELECTION AND GO-AHEAD
SERVICE
ALTERNATE FUEL
GO-AHEAD
SERVICE
HYPERSONIC
NEXT GENERATION SST
SHORT HAUL TRANSPORT (PASS.)
HIGH DENSITY
MED/LOW DENSITY
STOL/RTOL
GO-AHEAD
SERVICE

NEW TRANSPORT CONSIDERATIONS - CARGO AIRCRAFT

Continued growth in the demand for low cost rapid transportation of cargo by aircraft will lead to the development of new advanced cargo transports. An advanced technology medium to long range design, reflecting the same technology advances as its passenger carrying counterpart, could be operational in the late 1980's. This design, which may adopt powered lift concepts developed by the AMST program, would be lighter and offer lower operating costs than contemporary cargo transports.

A more advanced large cargo capacity transport is conceivable in the 1990's. Such a vehicle may have a take-off gross weight of over 1 million pounds, and be capable of carrying payloads of over 600,000 pounds for trans-Atlantic ranges. Flying wing concepts, such as Lockheed-Georgia's "Spanloader" aircraft, may be attractive configurations.

Another far term very large cargo vehicle that may emerge by the end of the century with proper support and development is a nuclear powered transport. Technology advances in large airframe design and manufacture; reactor design for low weight, ease of installation, and protection; heat exchanger development; and development of heat transfer materials must be carried out in much detail before such vehicles can be looked upon as being practical.


LOCKHEED CALIFORNIA COMPANY
NEW TRANSPORT CONSIDERATIONS
YEAR
75
80
85
90
95
CIAP STUDIES
AMST, CONCORDE B-1 SERVICE
MID TERM ENERGY PLAN
ADVANCED ENGINES
CURRENT TRANSPORT SERVICE LIFE
FAR TERM ENERGY PLAN
CARGO AIRCRAFT
NEAR TERM ADVANCED TECHNOLOGY TRANSPORT
SELECTION AND GO AHEAD
SERVICE
MILLION POUND TRANSPORT
GO AHEAD
SERVICE
NUCLEAR POWERED TRANSPORT
SELECTION AND GO AHEAD
SERVICE

NEEDED R&D PROGRAMS

Future air transportation technology needs will be satisfied if an ambitious R&D program is continuously maintained. The needs can be categorized into five areas of activity. Of highest near-term priority is noise and emissions research to find ways to relieve current problems with the existing fleet. These efforts should also look to the future for further alleviation.

Airport and airway congestion is a serious problem, and will worsen as passenger demand increases.

Means for meeting the energy shortages will become more necessary as time goes on. The change over to alternate fuels will have a major impact on aircraft and airport design and requires long development time -- research in this area should begin now.

New concepts and refinements that increase aircraft productivity should be actively pursued. These gains will not only provide more efficient air transports, but will also alleviate noise and emissions, and help conserve energy.

Safety is always an item of concern, and is of high priority requiring continued research.

Timing and details of these technology needs to the future transport time table previously discussed are shown in the next four charts.

LOCKHEED CALIFORNIA COMPANY

NEEDED R & D PROGRAMS

NOISE/EMISSIONS

- FAN AND JET NOISE
- HIGH BYPASS ENGINES
- AERODYNAMIC NOISE
- IMPROVED COMBUSTORS
- FUEL ADDITIVES

ENERGY CONSERVATION

- ADVANCED ENGINES
- NEW CONFIGURATIONS
- ALTERNATE FUELS

CONGESTION

- WAKE VORTEX ALLEVIATION
- TERMINAL CONTROL

INCREASED PRODUCTIVITY

- ACTIVE CONTROLS
- COMPOSITES
- SUPERSONIC CRUISE
- SUPER CRITICAL AIRFOILS

SAFETY

- CRASH WORTHINESS
- CLEAR AIR TURBULENCE
- EVACUATION
- TERMINAL AREA TRAFFIC CONTROL

TECHNOLOGY APPLICATION – NOISE/EMISSIONS

Noise alleviation of the early jet transports is of highest priority. Operating procedures (noise abatement take off, two segment approach) will provide immediate relief. Nacelle wall noise treatment (quiet nacelles) and engine retrofit (high bypass engines) is feasible. Near term relief of emissions can be obtained with revised combustor designs, and use of water injection. For any retrofit program, operating economy must not be seriously compromised.

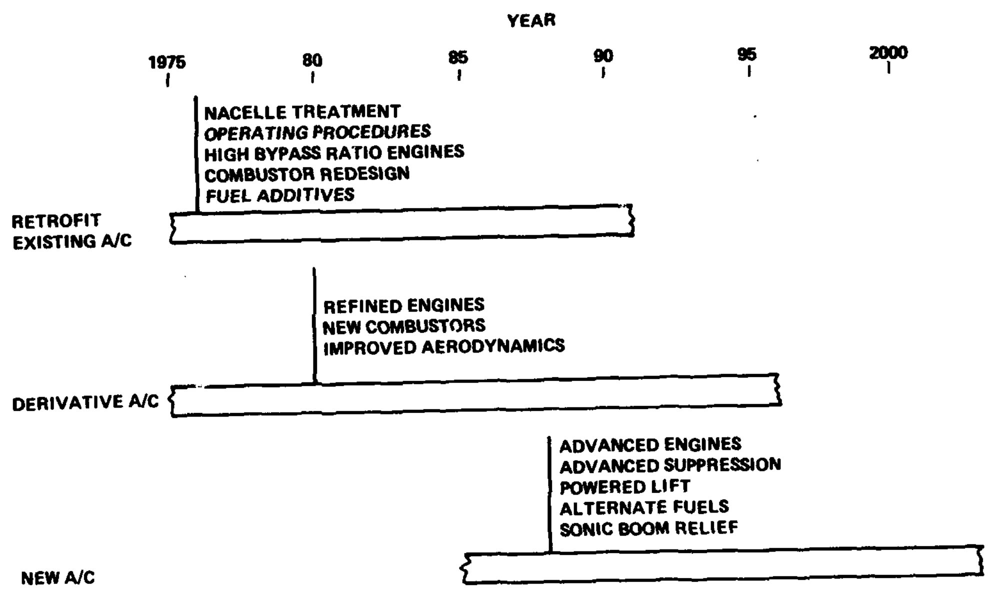
Derivative airplanes will adopt the newer quieter engine designs with improved combustors. Further emphasis on aerodynamic high lift concepts will help provide better lift-drag ratios and lower thrust (noise and emissions) levels.

New designs will incorporate new advanced engine cycles (variable pitch, two stage fans, variable turbine geometry) with jet suppression. Airframe shielding and powered lift to improve aerodynamic performance will be likely means for reducing noise. Lower gross weight aircraft with smaller power plants will be possible using clean burning, alternate high energy fuels.

Supersonic cruise vehicles will benefit from further research to find practical ways to reduce sonic boom intensity

LOCKHEED CALIFORNIA COMPANY

TECHNOLOGY APPLICATION - NOISE/EMISSIONS



TECHNOLOGY APPLICATION – CONGESTION

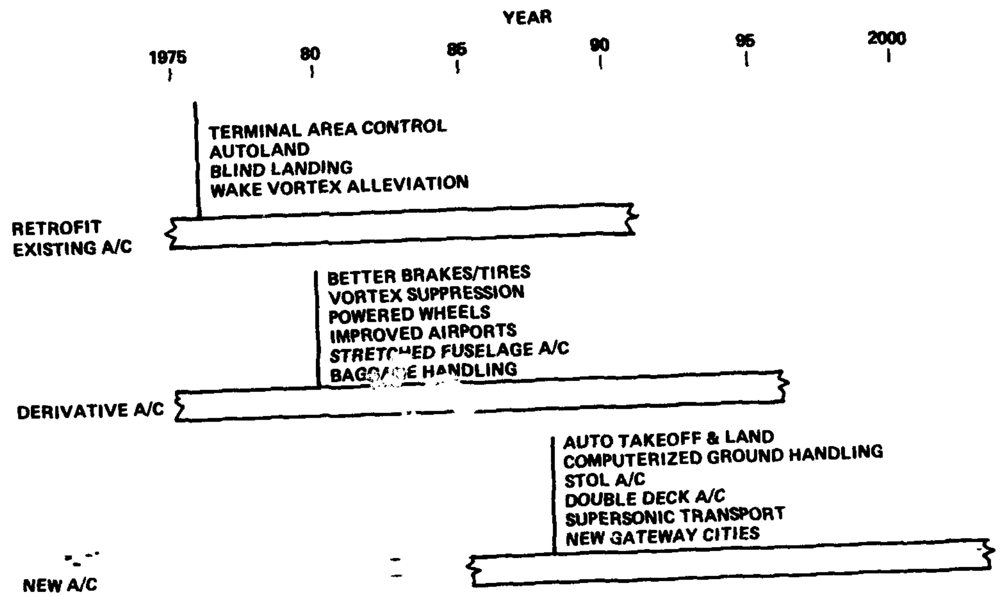
Relief from airport congestion requires more precise terminal area control, independence of airport operations from weather conditions, and ability to handle airplane arrivals and departures at faster rates. Avionics advancement and integration into the airplane can provide significant improvements. The extension of auto land capability, as currently employed by the L-1011 TriStar, to other aircraft and the steps to permit all weather blind landings should be developed; *retrofits* to selected existing transports should be possible. Simple airplane geometry changes may provide means for reducing wake vortex turbulence.

Derivative aircraft may employ advanced tires and brakes and active landing gear designs that will decrease runway occupancy time. High speed runway turnoffs also provide relief. Powered wheels could permit more efficient airplane ground handling. Larger capacity transports obtained by increasing the fuselage length of current airplanes provide means for handling greater passenger flow with fewer airplanes. New means for handling baggage must be examined.

New transport airplanes will employ further automated airport ground control guidance, including automatic takeoff and landing, and ground maneuvering. Double deck aircraft, to provide large capacities within reasonable fuselage lengths, will be developed. New means for emergency evacuation will have to be explored. Supersonic cruise vehicles can adpot new arrival and departure times that can relieve congestion.

Supersonic cruise vehicles operate at higher altitudes, and therefore provide airway relief. Reduced takeoff and landing capability (RTOL and STOL) will make available new terminal facilities and new means for handling local passenger commutation and transfer.

TECHNOLOGY APPLICATION - CONGESTION



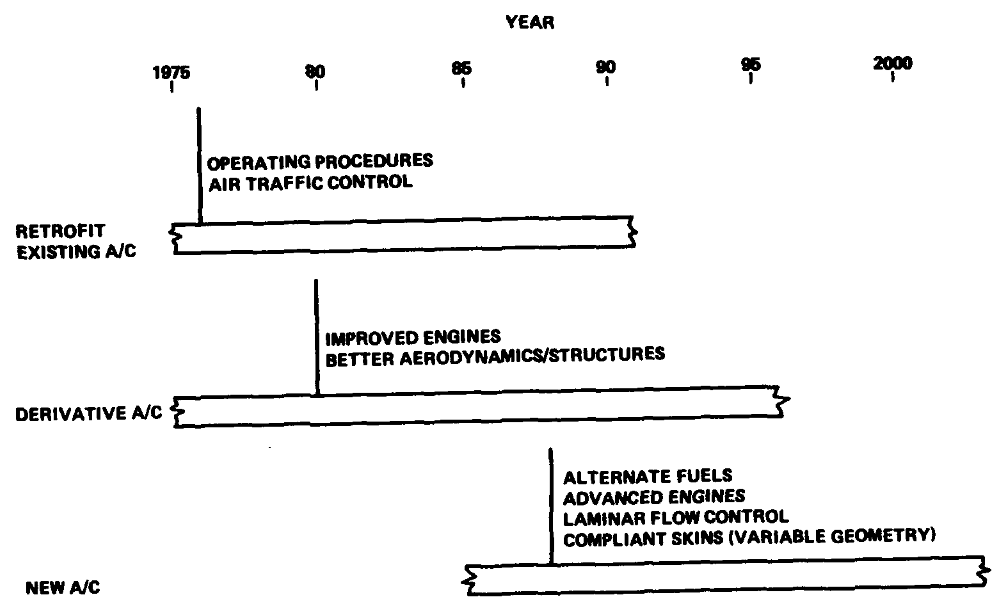
TECHNOLOGY APPLICATION – ENERGY CONSERVATION

All current transport aircraft reflect millions of hours of design and development study to minimize fuel consumption, and provide the most efficient operation possible. Therefore *immediate design changes to the existing transport fleet* to reduce fuel needs are not likely. Major gains are to be made in refining airport and flight management procedures, *to eliminate wasted time* as much as possible, and operate the airplanes as close to maximum efficiency as practical.

Derivative aircraft will adopt refined power plants, and utilize limited applications of advanced structures and aerodynamics as practical risk will permit.

The new generation transports *will reflect new engine cycles (advanced and variable cycle concepts) and* possible application of advanced technologies such as laminar flow control, or variable geometry (compliant skins that assume *minimum* drag shapes for various flight conditions). Fossil energy availability and sources of supply and production of alternate energy forms will influence future transports.

TECHNOLOGY APPLICATION - ENERGY CONSERVATION



TECHNOLOGY APPLICATION – INCREASED PRODUCTIVITY

The most beneficial long term advances in transport development will be those that improve productivity. Advances of this type require the greatest research and development time.

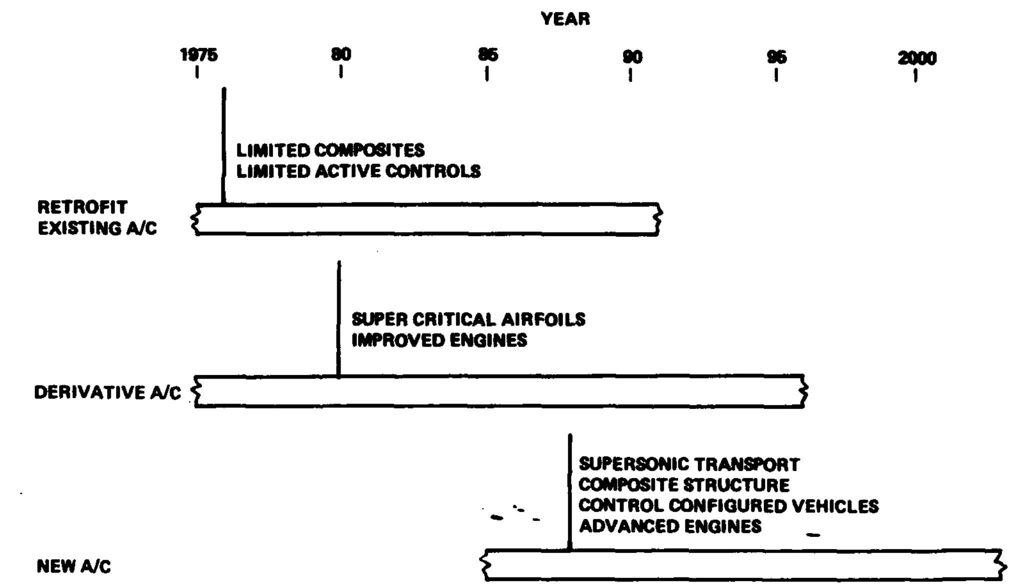
Limited applications of composite structure and active controls can be employed by the existing transport fleet. *Current aircraft* already use composite spoilers and fairings. Yaw dampers are relied upon for fatigue load relief. Studies of a composite material nacelle for the trijets is underway. More of these applications shall occur in the near future.

Derivative aircraft will adopt advanced supercritical airfoil wing designs that will *offer better cruise efficiency and lighter* structural weight. These transports will also adopt the newer more efficient high bypass ratio turbofan engines.

New transport designs will employ extensive applications of composite structure and active controls benefiting from the spin off of earlier applications to the existing and derivative airplanes. Advanced engine cycles will be available that are *lighter, cleaner burning, quieter, and more efficient.* Supersonic cruise speeds will offer substantial gains in productivity. New concepts of engine-airframe integration will be employed to provide lower drag, higher efficiency aircraft performance.

38-266 O - 74 - 21

TECHNOLOGY APPLICATION - INCREASED PRODUCTIVITY



PROGRAMS NEEDING MAJOR EMPHASIS

Many of the R&D programs required for future air transportation development are currently underway as part of the NASA Aeronautics program efforts. In certain areas, critical needs must be recognized, because (1) the needs are near term and immediate resolution would have enormous rewards, (2) the means for achieving them are complicated and need long development time, or (3) large technology advanced in these areas are seriously needed.

Near term efforts need to focus on ecology, congestion and fuel conservation, and a large portion of the research and development effort is properly oriented in this direction. Future efforts should include studies of wake vortex phenomenon. More use of the existing transport fleet as development vehicles should be exercised to help evaluate new ideas as they emerge from all these near term programs.

Propulsion is a key element in both near and far term research efforts. Engine/Airframe integration forms a part of this need, especially for advanced propulsion concepts.

Research and development of supersonic cruise vehicles should be continued to find ways to insure a successful second generation SST.

LOCKHEED CALIFORNIA COMPANY

PROGRAMS NEEDING MAJOR EMPHASIS

- TECHNOLOGY DEVELOPMENT USING CURRENT TRANSPORT FLEET (COMPOSITES AND ACTIVE CONTROLS)
- UNDERSTANDING OF WAKE VORTICES
- IMPACT OF ENERGY SUPPLY
- AERODYNAMIC NOISE OF LARGE AIRCRAFT
- ADVANCED ENGINE RESEARCH
- ENGINE - AIRFRAME INTEGRATION STUDIES
- SUPERSONIC CRUISE VEHICLE RESEARCH

LOWER PRIORITY TECHNOLOGIES

Efforts relating to hypersonic transport development and VTOL aircraft need not be high priority, since introduction *of these aircraft into service operation is not foreseen in this century. These items should be reduced in intensity, but* not abandoned entirely.

Transonic transports do not appear to have any practical merit, especially in light of current energy supply problems. These designs operate at cruise efficiencies which are reduced in exhange for small increases in cruise speed. The added complication and expense is not warranted — block time reductions are not significant when compared with delays encountered today because of congestion.

LOCKHEED
CALIFORNIA COMPANY

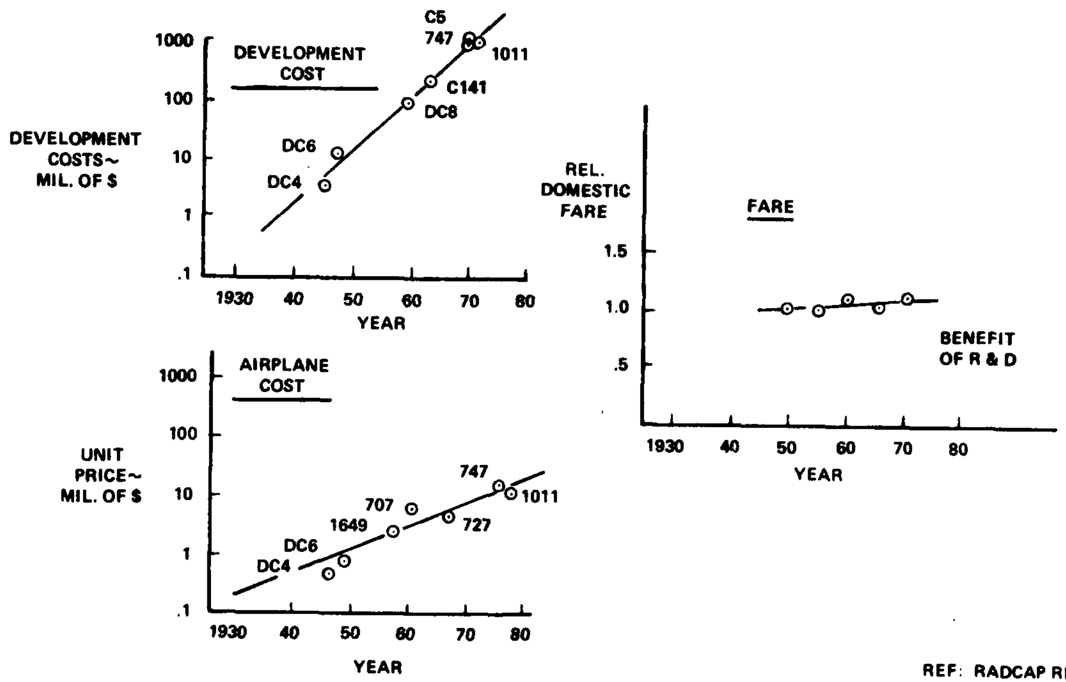
LOWER PRIORITY TECHNOLOGIES

- HYPERSONIC TRANSPORT DEVELOPMENT
- VTOL AIRCRAFT
- TRANSONIC TRANSPORTS (M = .98 - 1.4)

AIR TRANSPORTATION COST TRENDS

One of the most impressive returns from research and development expenditures in the past is the impact of R&D on transport aircraft productivity and operating costs. Despite significant increases in airplane development costs and unit price of transport aircraft, the cost to the traveling public for air transportation has hardly changed – domestic air fares have increased only slightly when current price fares (not corrected for cost of living index increases) are compared with those of 1950.

AIR TRANSPORTATION COST TRENDS



REF: RADCAP REPORT

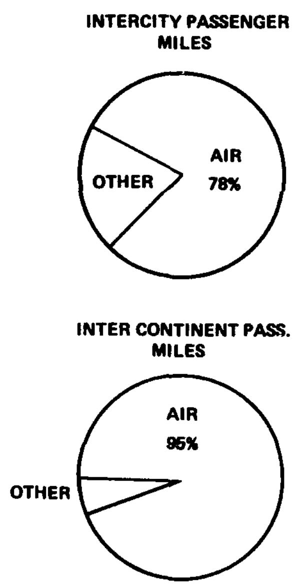
WHO USES AIR TRANSPORTATION

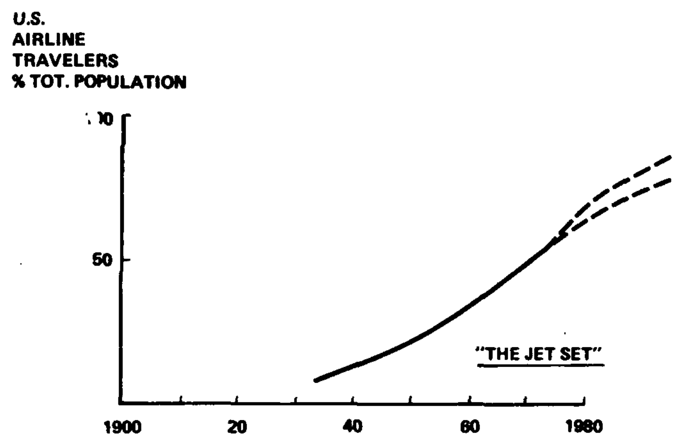
The public has been responsive to the improvements in air transportation. In 1973, *seventy-eight percent of all inter-city* passenger miles was provided by commercial airlines. Even more impressive, ninety-five percent of all intercontinental passenger miles was by air. The transport airplane has virtually eliminated travel by ocean liner save for luxury recreational purposes.

Over fifty percent of the total U.S. population over 18 years of age have traveled by commercial airlines. By 1985, over one million U.S. passengers will be boarding an airplane for travel, every day of the year. Thus, it is proper to define *today's air transportation system as a required* (and used) service of the whole nation rather than some small segment of the population.

LOCKHEED CALIFORNIA COMPANY

WHO USES AIR TRANSPORTATION





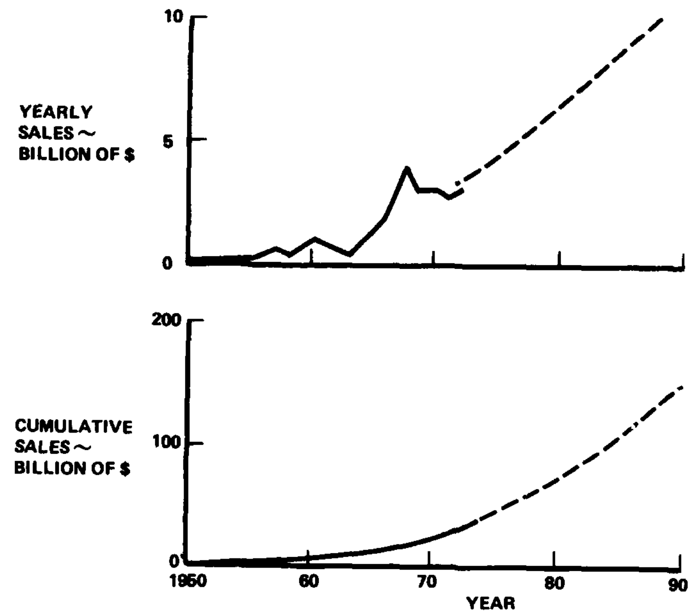
COMMERCIAL AIRCRAFT SALES POTENTIAL

Commercial aviation is big business. Sales of aircraft and powerplants have averaged over one billion dollars yearly since 1960. The cumulative sales since 1950 totals 40 billion dollars. Between now and 1990, over 100 billion dollars will be expended on new equipment, to meet the ever increasing needs resulting from passenger acceptance of air travel.

The industry has a major role in export trade and provides a significant element in GNP. It's dynamic nature and continued success requires continuing heavy development expenditures by the manufacturers and research expenditures by NASA.

LOCKHEED
CALIFORNIA COMPANY

COMMERCIAL AIRCRAFT SALES POTENTIAL



EUROPEAN COMPETITION

Future world airline equipment purchase dollars are not going to be reserved for purchase of *United States aircraft.* The foreign governments and industries are well aware of this lucrative future market potential and are anxious to capture a larger share with their own products. New foreign airplane programs supported by active R&D programs are underway, endorsed and sponsored by their governments who recognize the total economic value of air transportation to their nation.

These foreign quasi-national programs pose a serious threat to continued U.S. dominance in the world commercial air transport marketplace.

LOCKHEED
CALIFORNIA COMPANY

EUROPEAN COMPETITION

$ 4 BILLION GOVERNMENT PROGRAM

	GOVERNMENT SUPPORT	
CONCORDE	100%	$30 BILLION POTENTIAL MARKET
A300B	85	
MERCURE II	66	
VFW 614	80	

EUROPEAN FLEET MIX

TODAY – 90% U.S. MADE

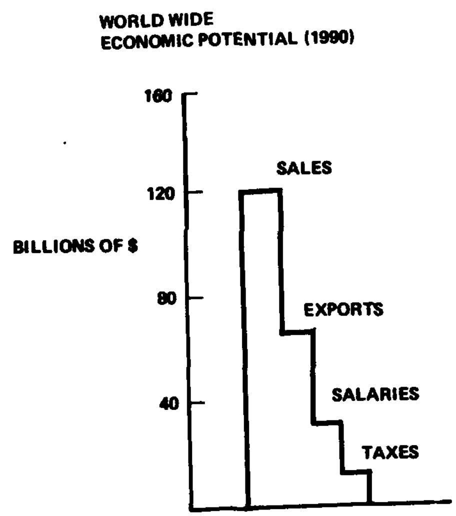
TARGET – 50%

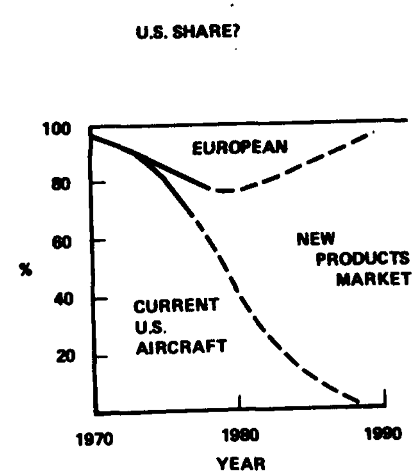
INVESTMENT IN THE FUTURE

By 1990, hundreds of billions of dollars in sales, exports, salaries, and taxes will have been expended in air transportation.

What will be the U.S. share? Current transport types and their derivatives will realize sales extending to the 1990's. The Europeans, who are striving for deeper penetration into the world market, are aiming to capture 20 to 25 percent of aircraft sales by 1980. Other nations also have national ambitions in this field. To offset these inroads and capture a major portion of the new products market, the U.S. must maintain the technically superior position it possesses today. This requires an aggressive commercial transport research and development program endorsed and sponsored by the U.S. Government. NASA Aeronautic R&D programs must be given a high national priority and a critical assessment of aeronautics versus space research expenditures is warranted.

INVESTMENT IN THE FUTURE





NASA R&D BUDGET

Presently allocated aeronautics funds are an undesirably small fraction of the NASA R&D budget. The wisdom and desirability of pursuing space activities is not questioned. However, the changing nature of the off-shore threat to the U.S. commercial air transport industry and the new low levels of military aircraft development suggest a review of national proprities and budget allocations.

To put the data in context, it may be noted that an insignificant 1 percent reduction in space expenditures benefits aeronautics by 11 percent at current budget levels. A full 50 percent enhancement only calls for a 4½ percent belt-tightning in our space programs.

In real terms (man-effort), the aeronautics allocation is remaining static, based on FY 73 to 75 allocations, while transportation demands and services are expanding, overseas competition is increasing, and parallel technology effort from military programs is declining.

LOCKHEED CALIFORNIA COMPANY

NASA R&D BUDGET

($ MILLIONS)

	FY 73	FY 74	FY 75
AERONAUTICS TECHNOLOGY	151	168	180
SPACE (MSF, SPACE SCIENCE, SPACE TECH., SPACE APPL., TRACKING)	2,337	2,137	2,061
	2,488	2,305	2,241

- 1% REDUCTION IN SPACE EXPENDITURES BOOSTS AERONAUTICS ELEMENT BY 11% – FY 75
- 50% ENHANCEMENT OF AERONAUTICS EXPENDITURES TAKES ONLY 4½% REDUCTION IN SPACE FUNDING

NASA FACILITIES PLAN

NASA's prime aeronautics tools – the major wind tunnels, laboratories, and equipment were built up in the 1930-1955 time period. Very low levels of funding have been applied since we have entered the space age.

The available facilities are falling into poor states of repair, resulting in high maintenance costs and low utilization. Needed new capability is not being obtained.

The FY 75 facilities allocation continues the trend – with 6.4 percent of the construction budget to aeronautics facilities – to permit the aeronautics tools to decline.

The combined effects of the levels of R&D budgets and facilities allocations in the aeronautics area are having a noticeable effect on the morale and effectiveness of the key aeronautical scientists within the NASA family.

LOCKHEED
CALIFORNIA COMPANY

NASA FACILITIES PLAN - FY 75

($ MILLIONS)

AERONAUTICS		SPACE	
AMES	3.66	GODDARD	2.11
LANGLEY	3.51	JPL	8.82
LEWIS	2.58	JSC	0.94
		LEWIS	.66
		MSFC	4.06
		WALLOPS	1.37
		VARIOUS LOCATIONS	7.47
		SHUTTLE FACILITIES	86.02
	9.75		111.4

AERONAUTICS	9.75	6.4%
SPACE	111.4	73.7
MINOR RE-HAB.	14.9	9.8
FAC. PLANS & DESIGN	10.9	7.2
MINOR C OF F	4.5	2.9
	151.4	100%

AIR TRANSPORTATION IS NOT FREE ENTERPRISE

It has been argued that the commercial sector should support its own R & D *needs in the future, without assistance* from government agencies such as NASA, on a theme of "a free enterprise industry should operate without subsidy."

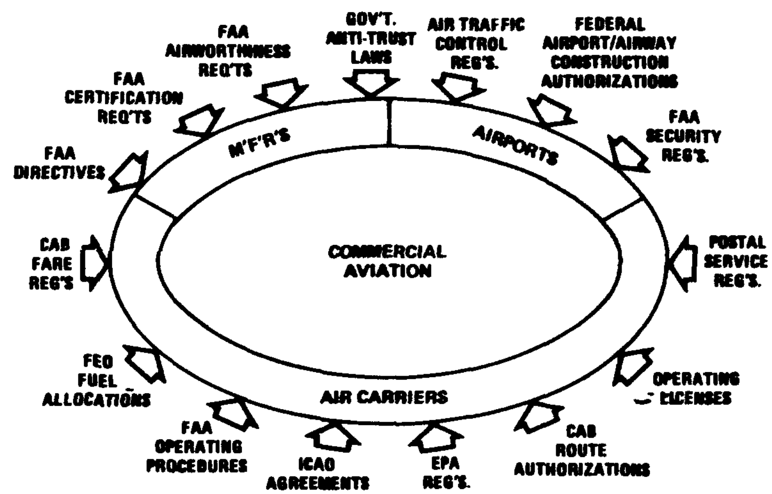
Air transportation is not free enterprise. The manufacturers, airport operators, and carriers are all partially regulated and directed by government *decree. These restraints are imposed to insure equitable distribution* of economic service for passengers in all parts of the nation, safety and reliability of service for these passengers, and protection of the industry from *unfair business practices. All forms of mass transportation have been, are,* and should be regulated to some degree to insure the best possible service levels for all.

The present air transportation scenario has evolved from operations under the regulatory constraints. Successful growth and world *leadership has resulted from the* benefits of NASA aeronautics R & D and military spin-off. Any reduced emphasis of NASA aeronautics R & D, combined with the planned reductions in military R & D applicable to commercial transportation and concerns over future energy sources, will bring about disastrous economic burdens on air transportation in all its segments.

Indeed, the need for increased well-planned aeronautics research and development must be nationally recognized. *Continued strong support* programs in R & D are an essential element of the future advancement of U.S. commercial aviation in world markets

LOCKHEED CALIFORNIA COMPANY

AIR TRANSPORTATION IS NOT FREE ENTERPRISE



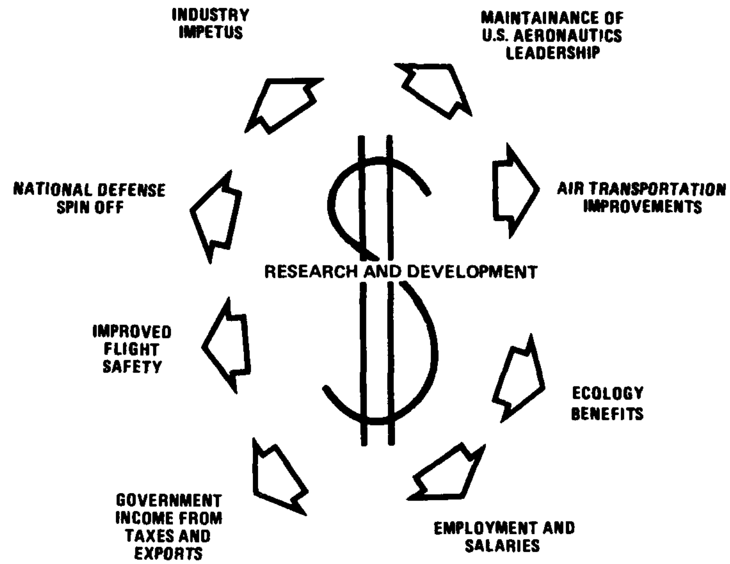
NASA R & D BENEFITS

Research in aeronautics benefits all Americans – even the non-traveler who will enjoy environmental improvements. By 1985, more than one million people per day will use air transportation in the U.S. Aerospace employment in this country involves 700,000 in direct employment. National benefits are widespread in exports, taxes, military spin-off and international prestige.

Research in aeronautics is a national asset because it assures preservation of U.S. leadership in world aviation in an era of increasingly serious competition from overseas. Past NACA, military and NASA R & D effort is the technical cornerstone of today's commercial air transportation system.

Continued -- and enhanced -- NASA aeronautics research and development is a national need of the first priority.

NASA R & D BENEFITS



North American Aircraft Group
Rockwell International

Dale D. Myers
President

1700 East Imperial Highway
El Segundo, California 90245
(213) 647-5595

July 29, 1974

The Honorable Frank E. Moss
United States Senate
3121 New Senate Office Bldg.
Washington, D. C. 20510

Dear Senator Moss:

In my letter of July 1, 1974, which was in response to your letter to Mr. Robert Anderson dated June 18, 1974, I indicated that we would be most pleased to provide for the record our comments regarding advanced aeronautical concepts.

As I mentioned, we are all quite enthusiastic about the XFV-12A advanced technology prototype program our Columbus Aircraft Division is conducting for the U. S. Navy. The enclosed paper provides highlights of the integrated augmentation concept which is applicable to this high performance V/STOL fighter as well as military and commercial transport and utility aircraft. The prototype is expected to fly next spring.

We consider this to be a very important program from a number of aspects. It is truly an advanced aerodynamic concept, totally new and unique; not just a percentage improvement. Although the basic principles of thrust augmentation have been around for some time, it is the integration of the augmented propulsive and aerodynamic forces which, we feel, can add a new dimension to aircraft operations. It provides a potential for practical point-to-point air operations without the constraints associated with

congested airfields or large aircraft carriers. We also feel that successful development of this concept will do much to sustain the leadership of our country in the world aircraft marketplace.

Another important advanced aircraft concept is under study at our Los Angeles Aircraft Division. This program, called AFTI (for Advanced Fighter Technology Integration) is managed by the Air Force Flight Dynamics Laboratory.

Although the program is not as far along as the Columbus V/STOL program, it has promise in bringing together in one flight vehicle, several advanced technology ideas which then can be tested as an integrated in-flight test bed.

I have also included a short paper on the AFTI program.

We are particularly pleased by your interest in advanced aeronautical concepts and grateful for the opportunity to submit the enclosed papers. I will be happy to provide additional information as our program develops.

Best personal regards,

Dale D. Myers

Dale D. Myers
President
North American Aircraft Operations

THRUST AUGMENTED WING CONCEPT

The desire to develop a high-performance fixed wing V/STOL aircraft has existed for over two decades. Many configurations have been tried; however, in nearly all cases the use of multiple or oversized engines for vertical take-off has severely limited the range and payload capability for a given sized aircraft. The helicopter has shown that the key to efficient V/STOL operation lies in the integration of propulsion, life and control into a single concept of flight. The helicopter, however, also has performance limitations primarily in speed and range.

Recently a new concept in V/STOL operation has been developed which, like the helicopter, integrates propulsion, lift and control for V/STOL operations as well as providing the high-performance advantages of the fixed wing aircraft. This concept known as the Thrust Augmented Wing (TAW) increases the vertical lift capability of an aircraft by directing engine exhaust air through ejector type thrust augmenters integral to the aircraft's lifting surfaces.

The principle of thrust augmentation has been known to physicists for some time; however, test apparatus required to achieve augmentation was not readily adaptable to aircraft weight and size restrictions. Recent technology incorporating the thrust augmentation principle into an integrated aircraft propulsion/lift/control system has resulted in relatively small, effective, lightweight augmenters capable of being folded into a conventional airfoil shape for cruise flight.

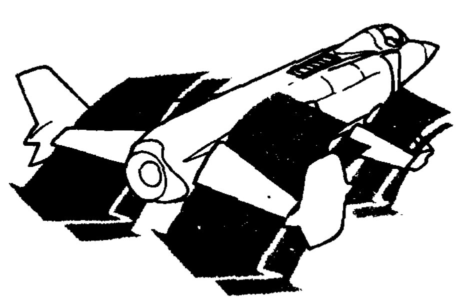


Figure 1.

Utilizing thrust augmenters in a wing/canard aircraft configuration, engine thrust and aircraft lift are distributed over four lifting surfaces. Modulation of these forces, either collectively or independently, allows aircraft attitude control to be completely integrated with the propulsion and high lift system.

AUGMENTER OPERATION

This thrust augmenter configuration consists of movable flaps which are rotated to a near vertical position for takeoff. Engine exhaust air is totally diverted and routed through ducts to the augmenter flaps where it is directed downward through thin full span slot nozzles into the diffuser area formed by the fore and aft augmenter flaps.

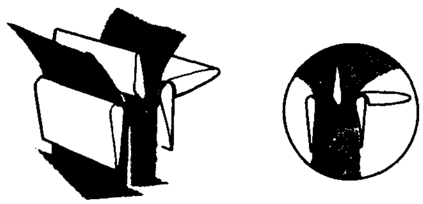


Figure 2.

This flow creates reduced pressure between the flaps inducing large masses of outside air through the augmenter. The resulting exhaust out the bottom of the augmenter is a low-velocity, high-mass flow mixture of primary and secondary air. The total output of primary and secondary momentum from the augmenter is greater than the input primary momentum. The ratio of total momentum output to momentum input is termed "augmentation ratio."

AUGMENTATION CONTROL AND INTEGRATION

While maintaining constant engine RPM, the thrust generated by this augmenter can be controlled by opening or closing the augmenter flaps. The resulting change in augmenter exit area increases or decreases the amount of outside air allowed through the augmenter. This geometry change controls secondary momentum and hence the augmentation ratio.

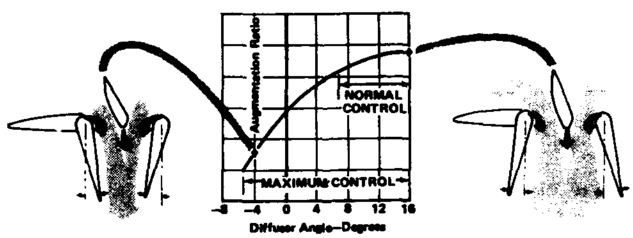
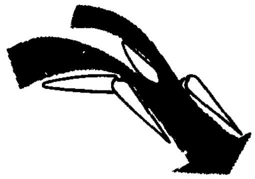


Figure 3.

The augmenter flaps may be rotated aft to allow the exhausted airflow to move rearward. The resulting forward tilted lift/thrust vector provides a horizontal force for forward acceleration. At slow forward speeds, a rapid buildup in circulation lift occurs due to the acceleration of secondary air over the aerodynamic surfaces. The high relative air velocity, particularly over the airfoil leading edge, produces lift far in excess of that attained by airfoil movement alone. This feature provides exceptional short takeoff capability.



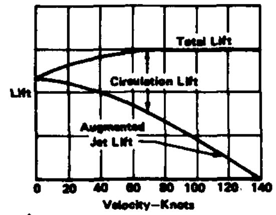


Figure 4.

The utilization of the thrust augmentation system to perform the functions of vertical lift, control and horizontal thrust provides the opportunity to develop an efficient integrated concept for V/STOL aircraft operations.

XFV-12A

The first application of the Thrust Augmented Wing concept is on the XFV-12A technology prototype V/STOL fighter/attack aircraft being built by the Columbus Aircraft Division of Rockwell International for the U.S. Navy. This aircraft uses thrust augmenters in the two forward canards and on either side of the rear-mounted wing to provide four lifting jets of air distributed about the aircraft's center of gravity. For the XFV-12A, a combined canard/wing augmentation ratio greater than 1.5 means that vertical lift can be obtained with an engine only two-thirds the size required by a direct jet lift system.

The engine exhaust is diverted at the tailpipe and ducted to the augmenters as shown in the illustration below.

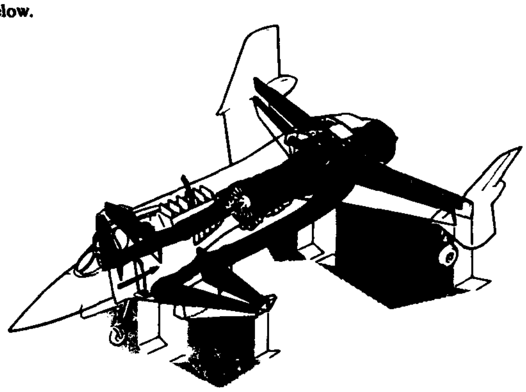


Figure 5.

The cool outside air induced through the XFV-12A augmenters, at a rate of about eight times the engine airflow, reduces the temperature and dynamic pressure of the engine exhaust air to provide the aircraft with a "footprint" with a magnitude between one-sixth and one-tenth that of direct jet lift concepts. This low-velocity downwash, with associated decrease in noise level, is compatible with flight support personnel operating in close proximity to the aircraft.

The lift generated by the four augmenters can be modulated collectively for vertical acceleration and hover control, or may be varied independently using normal cockpit controls to produce roll, pitch, and yaw. Pitch control is achieved by differential lift modulation of the canard and wing augmenters, while roll control is achieved by differential lift modulation of the wing augmenters. Yaw control is achieved by deflecting the wing augmenter flaps in opposite directions. This eliminates the separate reaction control system required for low-speed control in previous jet VTOL aircraft.

Conversion from vertical to conventional flight is accomplished as the pilot retracts the flaps. The forward tilted lift vector provides a horizontal component of force and accelerates the aircraft. During conversion, the wing and canard display characteristics similar to a jet flap as air is accelerated over the aerodynamic surfaces and through the augmenter. The supercirculation lift generated by this configuration builds up much more rapidly than aerodynamic lift alone. As the flaps are continuously retracted, forward speed increases until conventional wingborne flight can be maintained. At this point, the engine exhaust is redirected from the augmenters to the conventional jet tailpipe, and the flaps are fully retracted into a high-speed airfoil shape.

Figure 6.

A significant increase in payload may be obtained with take-off rolls of less than 300 feet. With the augmenter flaps preset to an intermediate position, approximately 60°, the circulation lift begins to build immediately upon brake release. Lift-off is followed by a relatively steep climb as the total lift continues to increase. Steep approaches with either vertical or short landings are advantageous in reducing noise and congestion at the landing site.

In the XFV-12A, the augmenter flaps are designed to serve multiple purposes. Since the wing and canard are both lifting surfaces, the full span trailing edge flaps are used as conventional aerodynamic control devices. Roll is obtained using the wing flaps, and pitch is obtained with the wing/canard flap combination.

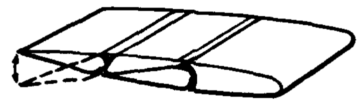


Figure 7.

Potential for direct control of lift during conventional flight is acquired by simultaneously deflecting the wing and canard flaps downward. Initial tendency of the aircraft then is to move straight up.

Figure 8.

By differentially deflecting the left and right canard flaps, it is possible to generate a direct side force on the airplane. Interconnecting rudder and flap movement eliminates roll and the airplane moves horizontally sideways.

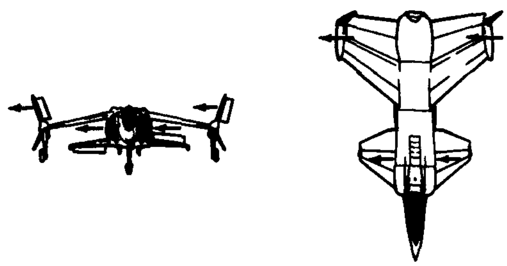


Figure 9.

In addition to performing the V/STOL functions of lift and control, the fore and aft augmenter flaps on the wings are used together during conventional flight to provide 90 square feet of speed brake area. This eliminates another separate system found on high-performance aircraft.

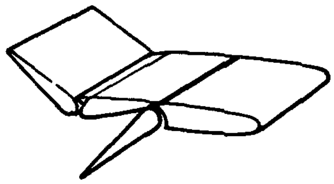


Figure 10.

ADVANTAGES
The smaller XFV-12A propulsion system made possible by this thrust augmentation principle requires less fuel for take-off than prior jet V/STOL concepts, as well as offering a more efficient propulsion/airframe match during conventional cruise flight. This advantage, combined with the greatly enlarged short take-off (STO) capability delivered by super-circulation lift, furnishes a significant increase in the range and payloads normally associated with nonintegrated V/STOL aircraft.

The large speed brake area available as well as the capability to maneuver using direct lift control (DLC) and direct side force control (DSFC), all using the same aerodynamic surfaces, offers potential air combat advantages heretofore unobtainable in military fighter aircraft.

FUTURE APPLICATIONS
The Thrust Augmented Wing technology may be applied to aircraft of varied sizes and mission applications. Attack aircraft based at operating sites close to advancing troops would ensure quick reaction to the ground commanders air support requests. The "deck loitering" of these aircraft has inherent economical advantages over the airborne flight.

The military airlift capability of transport and utility type aircraft, unrestricted by airfield availability, significantly increases operational flexibility. Resupply of Naval ships could be accomplished directly from shore bases without the requirement to land aboard large aircraft carriers and transfer cargo to helicopters.

Transport and multimission V/STOL counterinsurgency aircraft will be able to operate anywhere in the world independent of runway availability. Civilians can be rapidly extracted from potentially hostile areas where use of airfields has been denied.

As the cost of airfield construction and ground transportation networks continue to increase, and as the congestion at these facilities continue to expand, the advantages of V/STOL landing areas close to distribution centers become economically attractive.

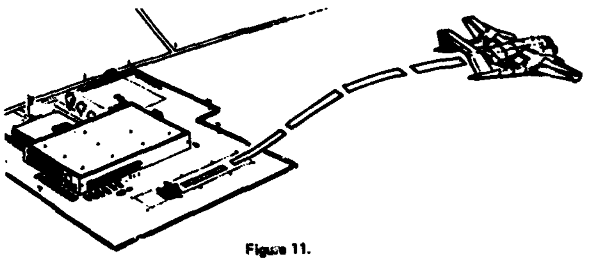


Figure 11.

V/STOL transport aircraft able to supply high priority items to remote sites prevent lost manhours and increase supply reaction time. Productive time lost while workers wait for unstocked equipment to be trucked hundreds of miles to austere areas in Alaska, for instance, could be extremely costly. Perishable products could be delivered by heavily loaded STOVL (short takeoff/vertical landing) transport aircraft directly to any point having a parking lot size vertical landing area. Current delivery methods quite often require several transportation modes with its attendant delays, increased administrative processes, and susceptibility to pilferage. Point-to-point air transportation tends to eliminate these disadvantages.

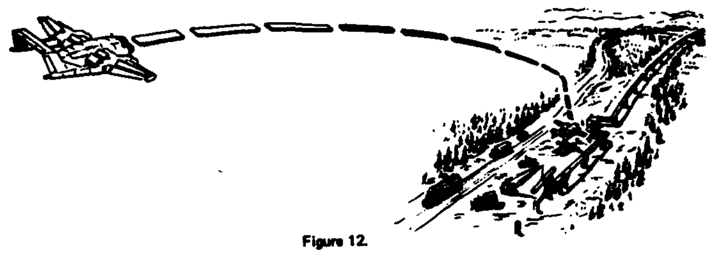


Figure 12.

Range and payload capability independent of airfield facilities is the real parameter for illustrating the advantages of V/STOL transportation. The concept of point-to-point air transportation using fixed wing V/STOL aircraft offers attractive economical advantages that are as applicable abroad as they are to the United States.

ADVANCED FIGHTER TECHNOLOGY INTEGRATION

One of the major programs currently underway to advance technology of modern fighter aircraft is the Advanced Fighter Technology Integration (AFTI) program. The Los Angeles Aircraft Division of Rockwell International is one of the contractors assisting the Flight Dynamics Laboratory in this program.

The development costs for new aircraft systems have risen significantly due to increasing complexity and performance required in modern warfare. The problem has been aggravated by failure of some systems to meet expectations after large expenditures of funds. The result has been that new systems have featured relatively minor technological advances in order to reduce schedule and cost overrun risks. Technical obsolescence will be a continuing problem in this environment because technology risks will continue to be minimized. A number of new and promising technologies have been developed to the extent that they show significant potential for enhancing vehicle performance and effectiveness. If these emerging technologies are to be incorporated into operational systems, and the potential synergistic benefits of integration of these technologies realized, they must be demonstrated to a level of confidence that meets the needs of low-risk systems.

The purpose of the AFTI program is to provide a mechanism for the orderly and evolutionary transition of new technologies into a low-risk status ready for transfer into future fighter systems. Flight demonstration of selected integrated technology can bridge the gap between development and system application, and reduce the risks of incorporating advanced technology without major program development. The ultimate payoff for the advanced technology demonstration vehicle will be the increased effectiveness and/or reduced cost of future operational aircraft which employ technologies incorporated into the demonstrator aircraft developed under the AFTI program.

Among those technologies being explored at Rockwell on the AFTI program are variable camber, propulsive lift (jet flap), direct lift/side force, advanced composites and metallic structures, improved control through integrated force management, and high acceleration cockpit.

Variable Camber - In the past, variable camber devices have provided a simple deflection of the leading and trailing edge of the wing. Because of discontinuities at the hinge lines, the usable lift has been limited. The discontinuities cause flow separation and shock wave formation with resultant drag increase. If the leading and trailing edges are extended at the

same time they are deflected, the desired camber line change is more nearly achieved. Mechanical and structural design considerations are the limiting factors on the amount of extension and deflection that can be achieved for a given wing planform and thickness.

Propulsive-Life (Jet Flap) - Our variable camber studies have shown that, for the range of wing aspect ratios and thicknesses of interest to the near-term AFTI, the range of attainable lift coefficients without separation or shock wave formation is limited to less than the desired levels, because, at transonic speed, the local lift outboard of 50 percent span is greater than can be sustained; therefore, shock result and drag increases. At constant total lift, the addition of a jet flap to the inboard section of the wing results in lower lift outboard at the critical section with the resultant elimination of the shock wave. It can be seen from the relative drag polars that the jet flap is an effective variable camber device, in addition to its propulsive lift, but the magnitude of improvement is a strong function of how well the mechanical variable camber device attains low vortex and wave drags.

Exploring and developing the synergistic effects of multiple technologies into a fighter-type demonstration air vehicle has shown the potential for greatly improving combat performance and maneuverability at high load factors in the high subsonic and transonic flight regimes. In addition, it is suggesting that this technology can be employed to develop aircraft concepts which efficiently cruise at supersonic speeds without the use of afterburning power in the engine. This concept, if technically verified, could provide the capability of employing totally different tacts and methods of fighter operations than are currently employed.

Therefore, it is anticipated that the AFTI program will transition new technologies into a lower risk status and permit this technology into future fighter systems.

PIASECKI AIRCRAFT CORPORATION

PRESENTATION TO THE COMMITTEE ON

AERONAUTICAL AND SPACE SCIENCES

UNITED STATES SENATE

SUBJECT: ADVANCED AERONAUTICAL CONCEPTS

STATEMENT OF: F. N. PIASECKI
PRESIDENT
PIASECKI AIRCRAFT CORPORATION

JULY 1974

STATEMENT OF

F. N. PIASECKI
PRESIDENT

PIASECKI AIRCRAFT CORPORATION

before the

COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES
United States Senate

Mr. Chairman and Members of the Committee:

Piasecki Aircraft Corporation was incorporated in 1955 by the founders of Piasecki Helicopter Corporation, which is now the Vertol Division of the Boeing Company. Since its founding, Piasecki Aircraft Corporation has been in the forefront of advanced aircraft design and development. During this time, a number of unique aircraft designs have been built and tested. Some of these are presented herein.

1. RING-TAIL

The PiAC Ring-Tail is an integrated system for converting a helicopter into a Compound-Helicopter, with significant increases in speed, range, altitude, maneuverability and reliability. A shrouded propeller with slip-stream deflection vanes replaces the helicopter's conventional tail rotor, and provides the anti-torque function in hovering flight, as well as propulsion and stability in forward flight. A small wing is also provided, which together with the Ring-Tail greatly reduces the dynamic loads on the main rotor and its drive system. Two models of Ring-Tail helicopters have been built and flown by PiAC, the 16H-1, (Fig. 1) and 16H-1A, (Fig. 2.) PiAC has conducted a design study for the Navy to convert the SH-2D helicopter to a Ring-Tail modification (Fig. 3) which would make a significant increase in its speed, speed at altitude and time on station in the anti-submarine warfare and anti-surface missile detection missions.

The Ring-Tail system for Compounding can be applied to new designs of Compound-Helicopters or to existing helicopter designs. The benefits received from this Compounding can vary, dependent on where the emphasis is placed in the design characteristics.

These improvements fall into three major categories:

(1) Performance

(2) Flying Qualities

(3) Maintenance and Reliability

Historically, performance has been the prime interest in Compounding helicopters for extending the high speed limits of helicopters, range and endurance. In the Army's "Advanced Aerial Fire Support System" (AAFSS) and in the Navy's ASW maneuvers for sonobuoy and M.A.D. operations, maneuverability of the Compound at high speed has been emphasized.

Recent studies, Ref. (a), have examined the effects of unloading the rotor dynamic system, both in thrust and in torque, on the fatigue/wear life of these components. The results show a large potential saving in the maintenance costs of helicopters, not only from the unloading, but from the reduced vibration levels in the entire aircraft due to the lower blade forces and from the axial flow pusher propeller in forward flight.

The practical value of the Ring-Tail Compound-Helicopter system to helicopter operations is significant from a safety standpoint. The Compound-Helicopter cruises with its rotor collective pitch in

a low setting and with the rotor in a plane parallel to the line of flight. Hence, upon a power failure, the time lag and the pilot control motions required to enter autorotation with the minimum loss of altitude are minimized, increasing the safety of flight, especially at low heights above the surface.

The enclosed tail propeller eliminates much of the hazard of the open tail rotor of the helicopter which has been dubbed the highest score killer item in helicopters by the U. S. Army.

Thus, summarizing, the Ring-Tail compounding of helicopters offers multi-faceted improvements to existing and future helicopters as follows:

Maintainability/Reliability

- Reduced fatigue loads in rotor dynamic components
- Reduced vibration

Performance

- Speed
- Range
- Endurance
- Cruise altitude
- Increase in gross weight growth potential

Handling Qualities

- Stability
- Maneuverability
- Level attitude
- Safety low level flight
- Safety ground personnel
- Lower noise levels

These advantages are applicable to both small utility aircraft as well as the larger transport aircraft. In the latter, the vertical force available at all times from the external elevator behind the Ring-Tail can provide a trim force to permit large center of gravity movement.

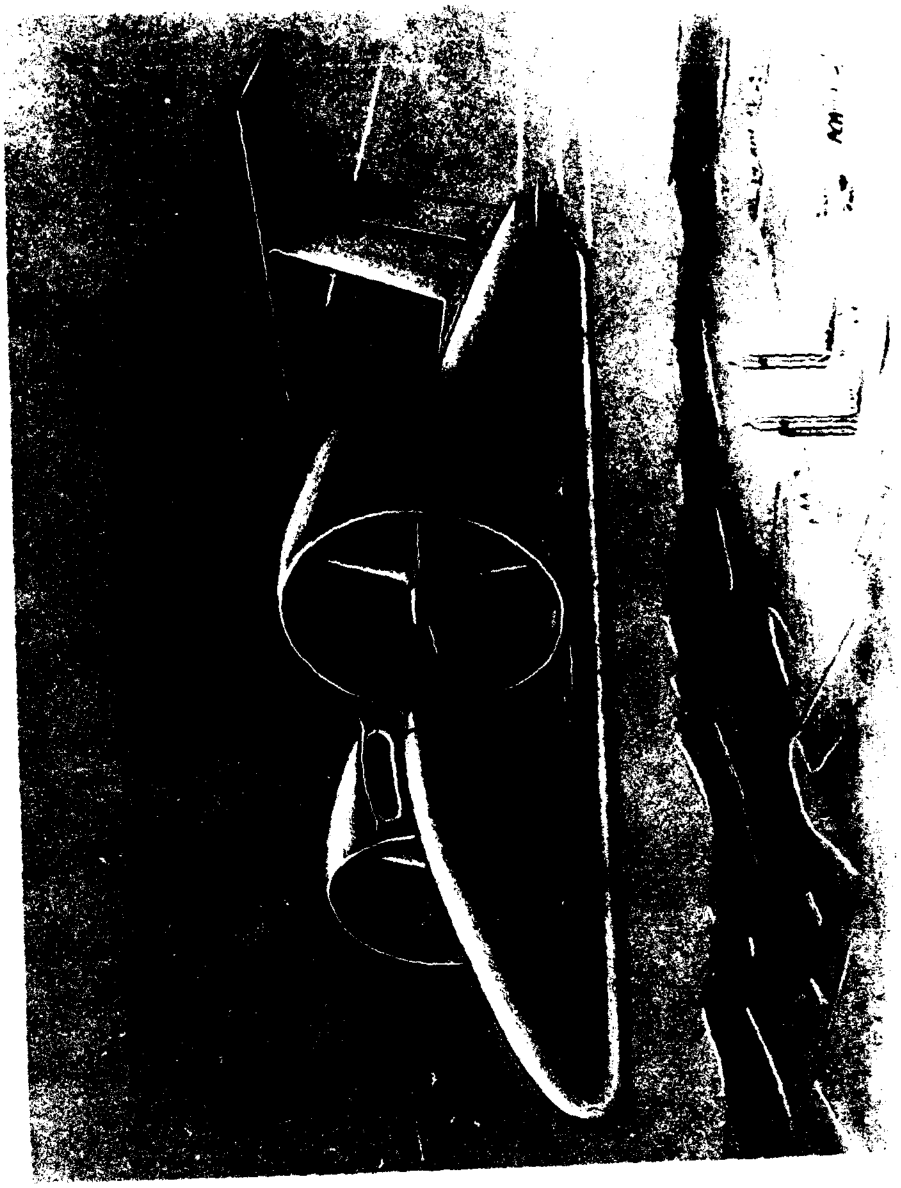
These improvements can make enough difference in the costs of operations ($/passenger mile), the productivity (passenger/miles/year), and the safety and comfort to passengers and neighbors, over current helicopter characteristics, that it is believed a new level of VTOL utilization can be achieved.

PIASECKI 16H COMPOUND V/STOL AIRCRAFT

FRONTISPIECE - SH-2D/RING-TAIL, VIEW FROM SUB

2. RING-WING

The PIAC Ring-Wing consists of a propeller mounted in a truncated shroud, with deflecting vanes in its exit area to turn the slipstream downward. In hovering flight, the vanes deflect the slipstream essentially vertically to provide hovering capability. In forward flight, the Ring-shroud, itself, at a small angle of attack, acts like a wing and supports the aircraft. The "Sky-Spy" design illustrates (Fig. 4) this type vehicle as an RPV, unmanned surveillance aircraft. High cruising speed for survivability, quick reaction time, as well as a hovering capability to "take a better look," and to permit operation into and out of unprepared sites would be the key feature of this aircraft. A wind-tunnel model of an attack aircraft type utilizing this configuration is shown in Fig. 5.

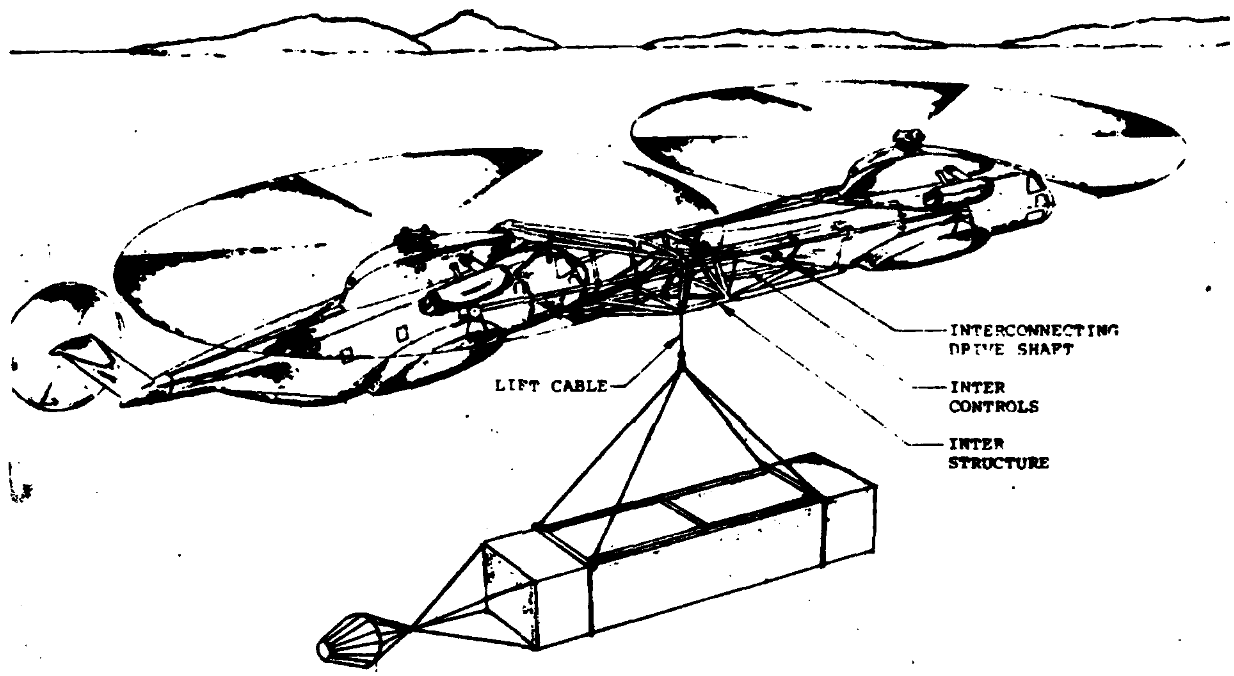


3. MULTI-HELICOPTER HEAVY LIFT SYSTEM (MHHLS)

Lifting loads far beyond the capability of the largest current helicopter, without the necessity of developing new technology or a new, larger helicopter, is the objective of this concept. Two or more existing helicopters are modified so that they can be rigidly interconnected and flown as a single vehicle, adding their lift capability. The rotor drive systems are interconnected to provide a high degree of redundancy against powerplant failure. The control systems are also interconnected, so that the entire assembly is flown from one cockpit. (Fig. 10)shows two CH-53D helicopters coupled in an assembly which, as shown in a design study (Ref. 8) for the Navy, could lift a payload of more than 18 tons. With the larger model CH-53E it could lift 32 1/2 tons.

In order to meet the USAF need for lifting minuteman missiles in and out of silos, to altitude for free drops, and other missile transportation functions, a design study was made of this MHHLS concept in the 40 ton capacity size and with speeds in excess of 230 kts. and altitudes over 20,000 ft.

The MHHLS system could be designed, built and tested for a small fraction of the cost of a new Heavy Lift Helicopter. In addition, the individual helicopters can be disassembled into their individual entities and used for smaller payloads during times when the heavy-lift capability is not required, or for stowage below decks.



MULTI-HELI HEAVY LIFT SYSTEM (MHHLS)
TWO CH-53D UNITS IN TANDEM

39-X-11 Fig 10
Fig 10

4. <u>AEROSTAT AND MULTIPLE HELICOPTER LIFT SYSTEM (THE HELI-STAT)</u>

For ultra large payloads, and without having to develop a new technology, PIAC has conceived the Heli-Stat. Four or more existing helicopters are coupled by means of rigid structure to a large, unpowered aerostat of streamline shape. The helicopters are free to pivot at their junctions to the structure, so that they can furnish both lift and propulsion to the assembly(Fig. 11). The aerostat has sufficient lifting capacity to support the weight of the helicopters and their interconnecting structure. Thus, all of the thrust produced by the helicopter rotors is available to lift and propel the payload. Such a combination has a payload potential greater than the aerostat alone would have, or the helicopters in combination (as in the MHHLS). PIAC has studied designs with payloads from 65 tons to 280 tons. Still larger payloads are possible.

The placement of the interconnected helicopters at large distances from the center of the assembly with their high contribution to the lift, provides large control moments.

Thus, the Heli-Stat with this precision and powerful control eliminates the large ground crew requirement of past dirigible operations and allows this lift to be utilized in crane operations where placement of loads in their desired final position is required.

Thus, the Heli-Stat can land safely in unprepared areas, and in standard air fields without special equipment.

38-266 O - 74 - 24

The technology involved in the preceding developments are represented by patents in the United States and foreign countries, and in-Company know-how, both of which are available for licensing, world-wide.

REFERENCES

NO.	REPORT NO.	CO. OR AGENCY	TITLE	AUTHOR	DATE
a.	316-X-7	Piasecki Aircraft Corp.	Application of Ring-Tail System to the SH-2D Helicopter and Resultant Improvements in Performance, Maintenance and Safety	D.Meyers et al	March 1973
b.	159-X-36	Piasecki Aircraft Corp.	Preliminary Design Study of STAMP (Small Tactical Aerial Mobility Platform)	D.Meyers et al	30 Nov.73
c.	39-X-11	Piasecki Aircraft Corp.	Multi-Helicopter Heavy Lift System, Feasiblity Study Final Report	D.Meyers et al	Feb. 1972

STATEMENT OF CHARLES EMERY ROSENDAHL
Vice Admiral, USN, Retired

Mr. Chairman and Members
U.S. Senate Aeronautics and Space Sciences Committee: 4.5-7M 9

As one who has had operating experience and responsibilities in the field of airships; has studied their records and performances; and remains a believer in such craft, permit me to express my gratitude to you gentlemen of this Committee for your willingness to take an active interest in the current consideration being given to the revival of airships.

The views and comments presented herein are strictly and solely my own. I have no affiliation, actual or potential, with any concern or individual who stands to gain from an airship program should there be one. Moreover, I have had no part whatsoever in the current airship propaganda being showered upon the public.

Furthermore, I see no use, at this moment at least, of "x-raying" such a surfeit of propaganda as the volumes of spoken and written words and the assorted "artists' conceptions" of the helium behemoths now aloose in the dreamworld, except to note a simultaneously incited, legitimate curiosity as to whether such dreamboats could actually perform the deeds being prophesized for them.

The public has the right to wonder why nearly three-score years after our country first became interested in airships, we are now at a stalemate in both rigid airships and nonrigid airships (blimps).

During World War II we operated blimps with marked success in their specified missions: on the Pacific Coast from border to border; in the Gulf of Mexico; along the full length of our Atlantic Coast; in the Caribbean; along Central and South American East coasts down to below Rio; and also in the Western Mediterranean. We evolved a very satisfactory blimp and its equipment, that could be revived and placed in useful services today. After deliberate nefarious chipping away at them even during the War, in 1962 the Navy Department on the flimsiest of pretexts abandoned blimps altogether.

With respect to the rigid airships, those in authority over them have shamefully let the world draw the utterly ridiculous conclusion that the United States lacked the ability to design, manufacture, and operate such aircraft successfully in important fields.

No knowledgeable person disputes that in practically every new project of any consequence, a period of pioneering "trials and tribulations" is expected - or is "par for the course" it might be said. But what is not generally realized is the great extent to which human prejudices and unwarranted bias have been responsible for our present airship

stalemate. Let me assure you, however, that it has been of major significance. Having witnessed so much of this first-hand, it is my opinion that this is a matter for recording in written history. The bulging manuscript for this book is practically complete, my one remaining problem being what to leave out to keep it to one volume.

What faces us at the moment is whether we should revive a rigid airship program; so here are some of my thoughts on the matter:

(a) Remember that the field of air transport does not belong solely to one form of aircraft but can accomodate and utilize each of such specialists as the airplane, the flying boat, the airship and the helicopter. On land, at sea, and in the air it is appropriate specialists that provide us transportation.

(b) The rigid airship is primarily a transoceanic vehicle for long distances, though obviously it has to cross some land to get to and from the sea from its terminals.

(c) Forget regular transcontinental or overland service for rigid airships or be prepared to come to grief.

(d) Resume airship service (transoceanic) on a freight or cargo basis. In time some passenger business too will come to the oceanic airship.

(e) Insure an adequate prototype or "shakedown" period before placing the ship(s) in service. Knowing human nature, I venture that this will be the toughest condition to fulfill.

(f) Provide such safeguards, probably legal, that airship authorities cannot shirk any portion of the airship program assigned to them severally or collectively.

(g) Decide on the initial prototype(s) to be built, but provide for a continuing research and experimental activity into which to direct promising speculative types that may be offered, and to provide updated improvements in already existing types. Don't waste years on dreamboats.

(h) Resume rigid airship construction with an already proven type, making it legitimately larger if practical and otherwise advisable.

(i) For purposes of (h) the HINDENBURG (LZ-129) was by a wide margin the best rigid airship ever built and put into service. The later LZ-130 was probably even slightly better.

Certain modifications, none too costly from any standpoint, would make the resultant ship an even better one in important respects.

I have in mind certain modifications and would gladly pass them along to the agency eventually to be charged with such production.

It would be very advisable to construct and operate two prototypes simultaneously.

(j) On the basis of past performance and attitudes, keep the Navy out of the airship revival program.

(k) I stand ready, at your request, to supplement anything I have said or indicated herein.

(l) Starting from scratch, American technological talent startled the world by its amazingly successful program in space.

I for one refuse to entertain even the slightest thought that American technological genius cannot make a success of modern airships too, particularly having the eminently successful HINDENBURG type as the starting point.

C. E. Rosendahl

July 1974 C. E. ROSENDAHL

Office of Vice-President UNITED AIRCRAFT CORPORATION

31 July 1974

Honorable Frank E. Moss
Chairman
United States Senate
Committee on Aeronautical and
Space Sciences
Washington, D.C. 20510

Dear Mr. Chairman:

United Aircraft Corporation welcomes this opportunity to respond to the invitation issued by the distinguished Chairman of the Senate Committee on Aeronautical and Space Sciences. We are happy to submit some of our views on Advanced Aeronautical Concepts for inclusion in the Record of your current hearings. These views cover the areas of interest mentioned in your news statement of June 14, 1974, with one exception -- lighter-than-air vehicles which has not been a subject of our immediate interest in recent years. We certainly agree that the United States is not putting a sufficient effort in advanced concept development areas to assure a continued dominance of the commercial aircraft market.

One such area is the development of technology necessary for a viable contender for a future SST.

Both in Europe and in Russia, large scale efforts are being underwritten to develop a supersonic transport for commercial application. It is unlikely that the first-generation aircraft produced by these programs will be fully acceptable or profitable. However, these programs are developing the expertise and the experienced teams that could provide the base for development of a viable second-generation aircraft. If such an aircraft were produced, it would capture a significant portion of the future commercial long-range transport market. The question we face is whether or not the U.S. can afford to leave itself unprotected against such a threat.

The present NASA-supported Advanced Supersonic Technology (AST) program was conceived as a low-cost means of protecting the U.S. future in the long range transport market. New concepts are being sought to overcome the technical problems which contributed heavily to the 1971 decision to cancel the United States' earlier SST effort.

EAST HARTFORD 8, CONNECTICUT

Specifically, the NASA program aims to provide the technology to meet tomorrow's challenge of a profitable SST within acceptable ecology standards.

New concepts are emerging from the NASA AST program. The Variable Cycle Engine is one such concept. The Variable Cycle Engine will combine the best features of a turbojet engine, which gives the best performance at supersonic speeds, and a turbofan engine which has the best performance at subsonic speeds and low noise characteristics. This will significantly improve the performance of the overall aircraft system, conserve fuel, and, we believe, permit engine-generated noise levels to be competitive with today's wide-bodied transport aircraft.

Funding of the NASA AST program to date has been adequate to conduct the initial conceptual and analytical studies to provide the basis to our future SST technology programs. However, a significant increase in this funding will be required to make significant progress in developing the technology needed for initiation of a new SST development program.

A phased program is recommended to complete, verify, and utilize the supersonic transport propulsion technology base.

During the first phase, which would occur over the next two to three years, detailed design and evaluation studies would be made of the most promising engine concepts. In addition, airframe/engine installation studies would be conducted, and the necessary component technology programs carried out. At the end of this phase, the viable component concepts would be identified and the cycle characteristics sufficiently defined to permit selection of a design for experimental engine testing. The second phase would involve a three to five year program to fabricate and test an experimental engine. Particular emphasis would be placed on demonstrating the performance, noise, and emission characteristics. At the end of this phase, the viability of the candidate design approach would be established, thereby providing the desired technology base for initiation of a supersonic transport engine development program. If the results of Phase II and the competitive situation warranted continuation, the third and final phase of the program would consist of the final engine development. This would result in a qualified engine for the second-generation supersonic transport.

The results of this program would put the United States in a good position to compete worldwide for the second-generation SST by the end of this decade.

A second area of concern is that of fuel conservation in future subsonic aircraft. Looking at the historical picture, we see that the fuel consumption of aircraft gas turbine engines has steadily improved. We project that this improvement will continue. This improvement will not be easy to reach nor will it be inexpensive.

The main variables in a gas turbine engine design that affect fuel consumption are (1) bypass ratio (the ratio of the amount of air discharged overboard from the fan to the amount of air going through the core of the engine), (2) overall pressure ratio (the ratio of the pressure of the air leaving the compression system to the pressure of the air entering it), and (3) the turbine temperature (temperature of the gas leaving the combustion chambers and entering the turbine).

The specific fuel consumption of future engines can be improved by a continued trend toward higher bypass ratios, higher pressure ratios, and higher turbine inlet temperatures. Potentially, fuel consumption could be reduced by 15 percent if bypass ratios were increased to 10:1 (from the present values of 5:1), pressure ratio to 40:1 (from present values of 25:1), and cruise turbine inlet temperatures to 2500°F (from present values of 2200°F). Improved technology would be required to achieve these design objectives without loss in component efficiency, without increased amounts of cooling air or air leakage, without compromising engine durability or reliability, and without an excessive increase in weight due to the large fan. This level of technology will not be easy to reach. A few of the key technology developments required are: improved materials for the hot end of the compressor; more efficient cooling schemes and improved materials for the turbine; closer clearance control, particularly in the high pressure portion of the engine; more effective air seals through improved design and materials; lightweight fan blade and case structures integrated with the nacelle and using composite materials; improved burner designs that will operate at the higher temperature levels with acceptable levels of emissions.

Studies have shown that variable pitch fans, variable area turbines and variable area engine or fan duct nozzles can potentially provide improved fuel consumption in future engines at off design conditions. This is accomplished by adjusting the areas to provide more efficient component operation and/or a better thermodynamic cycle. This needs to be accomplished without a significant penalty in turbine performance and durability, and without excessive exit nozzle weight. Continued study of these variable features in future engines is indicated. Design and testing is re-

quired to develop the technology needed for a practical, durable, efficient variable area turbine to operate at future turbine temperature levels.

There are a number of more complex designs which have potential for further lowering fuel consumption. One of these is the regenerative engine, which uses a heat exchanger to capture waste heat energy from the exhaust.

The present energy crisis and sharp increase in fuel costs have created an urgent need to generate advanced technology to reduce the amount of fuel consumed by the next generation of commercial transport aircraft. An aggressive R&D funded program in this area is needed to assure continuance of a competitive U.S. position in the world market.

A third area of concern is that of intercity transportation in congested corridors of activities becoming critical in our country due to limitations of airport facilities. Since it is difficult to obtain and develop real estate for new and larger airports near to city hubs of interest, alternate means must be sought to relieve this problem. Thus, an unusual opportunity exists in the development of intercity transportation systems based on aircraft capable of vertical takeoff and landing.

To meet this requirement and assure continued American dominance of air transportation systems, a two-phased program is suggested. The first phase should be a demonstration of the feasibility of high speed (150 knots) VTOL intercity transit using large transport helicopters such as the Sikorsky S-65C. The second phase would be a longer range development of a higher speed (230 knots) compound VTOL which would have higher productivity and lower operating costs. Since large high speed (150 knots), economical ($40. ticket cost for New York to Washington trip of one hour and 20 minutes), VTOL transports are available in the form of the S-65C helicopter; a means is needed to demonstrate these attributes.

It is recommended that NASA finance and supervise a one-year demonstration of VTOL airline service between two major cities in the Northeast Corridor to demonstrate reliability, economics, ride comfort, customer acceptance, and public service of a new mode of transportation.

Larger capacity, longer range, more economical VTOL transportation can be provided by a compound VTOL such as the Sikorsky S-200. The S-200 fuselage contains 86 passenger seats, two lavatories, 60 cubic feet of storage for carry-on baggage, and 450 cubic feet of baggage space below the floor. The S-200 cruises at 230 knots and provides a 230 mile range. The external noise of the compound has been minimized through unique design features.

It is recommended NASA continue funding the rotor systems research aircraft to develop the S-200 rotor/propulsion system by 1976. To further minimize the technical risk of the follow-on S-200 development program, it is recommended NASA fund further work in the large S-200 compound such as wind tunnel testing, propulsion system development, etc.

A fourth area of concern is associated with air traffic control. Increasing the reliability and accuracy of an air traffic controller's function ultimately improves the safety of an air traffic system and allows operation under extended circumstances. In the interest of improving controller response time, research has been conducted on the addition of color to air traffic control displays. We have built a retrofit kit providing color for a government-furnished display. Laboratory evaluation of the safety improvements provided by this display has been conducted at the FAA's NAFEC facility for the last year. Since these experiments are expected to show a significant improvement in safety of performance, we urge that field evaluation and implementation begin as quickly as possible.

The fifth area of concern is associated with the basic and advanced limited research being conducted in our country. In order to maintain our preeminence in the worldwide aeronautical industry, we urge that the proven capabilities and resources of NASA be supported in such developments and research as:

A. Development of structural design criteria of composite and compound materials having non-isotropic properties. Non-destructive methods of examination must be developed to assure quality control consistent with our safety requirements. The use of computers in the application of these new materials.

B. Structural research is encouraged to provide a greater level of survivability in the event of crash conditions. In particular, research on energy absorbing structural deformation should be encouraged.

C. A continuation of reserach leading toward reduction of the seriousness of post-crash fires. Research in areas of fuel and fuel systems are encouraged.

Sincerely yours,

W. A. Kuhrt

W. A. Kuhrt
Vice President-Technology

WAK/w